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ADVANCED ROTORCRAFT TECHNOLOGY AND TILT ROTOR WORKSHOPS

DECEMBER 2-5, 1980
PALO ALTO, CALIFORNIA

VOLUME IV
Flight Control, Avionics Systems and Human Factors Session

HAA/NASA

ADVANCED ROTORCRAFT TECHNOLOGY

WORKSHOP

December 3-5, 1980
Palo Alto, California

VOLUME IV

FLIGHT CONTROL, AVIONICS,

AND HUMAN FACTORS

VOLUME IV

FLIGHT CONTROL, AVIONICS, AND HUMAN FACTORS

CONTENTS

CHAIRMAN'S REPORT

This volume presents the flight control, avionics, and human factors segment of the workshop. This includes the identification of user needs as pointed out by the user presentations on the first day, combined with a summarization of the proceedings of the specific flight control, avionics, and human factors technical session. The technical session format consisted of opening remarks by the session chairman, description of the NASA technical program, followed by manufacturer presentations in a) a Flight Control Technology subsession, and b) an All-Weather Operations subsession.

Technical session participants were as follows:

Session Chairman:	Kenneth Jones Offshore Logistics, Inc.
Technical Secretary:	C. Thomas Snyder NASA-Ames Research Center
Recording Secretary:	Richard Kurkowski NASA-Ames Research Center

Description of NASA Technical Programs (Briefing material for these presentations are contained in Appendix A of this volume).

NASA Helicopter Flight Dynamics & Control Research
Robert Chen

NASA All-Weather Rotorcraft Program
John Bull

NASA Helicopter Man-System Integration Program
Ed Huff

Flight Control Technology Subsession (Briefing materials for these presentations are contained in Appendix B of this volume).

Bruce Blake
Boeing Vertol

Rod Iverson
Sperry Flight Systems

Dora Strother
Bell Helicopter Textron

David Key
U.S. Army Aeromechanics Laboratory

Ted Carter
Sikorsky Aircraft

All Weather Operations Subsession (Briefing materials for these presentations are contained in Appendix C of this volume).

Ken McElreath
Collins Radio

Paul Pencikowski
Hughes Helicopters

Richard Cnossen
Magnavox

Larry Clark
Heliflight Systems

SUMMARY OF USER NEEDS AND TECHNOLOGY REQUIREMENTS

The following summarizes user needs, technology requirements and status, and proposed R&D action. This summary is divided into three sections: Flight Dynamics and Controls, All Weather Operations, and Human Factors. The shorthand form of the summary of this segment of the workshop is included as Table I. The discussion follows the order used in Table I.

FLIGHT DYNAMICS AND CONTROLS

Helicopter flight dynamics and controls related user needs and technology requirements are summarized for six categories: Certification Criteria, Optimum Take-Off Techniques, Heavy-Lift/Multi-Lift, Flying/Ride Qualities, Operational Reliability, and Low Altitude Turbulence Velocity Profiles.

Certification Criteria

The need in this area is to help develop criteria which the FAA can use to develop standards relative to rotorcraft controls and displays and the dynamic behavior of the total vehicle. NASA has been working jointly with the FAA over the last several years, looking at various aspects of the problem. The technology requirements can be broken down into basic stability requirements, dual/single pilot IFR requirements, simulator requirements for certification testing, and software verification and validation requirements for digital systems.

Stability Requirements - There is a continuing need for a stability, control and handling qualities data base as design information and a current need for the improvement of certification criteria. Investigation of possible relaxed static stability requirements was urged by a manufacturer representative. Investigations were urged to better understand stability boundaries of high gain control systems, and should include improvements of dynamic inflow modeling and wind tunnel/flight test correlation of dynamic derivatives. Ongoing joint NASA/FAA research includes simulation and flight investigations with the goal of providing data for revision of air-worthiness standards for helicopter IFR operation, with stability requirements and improved inflow math modeling being specifically addressed.

Dual/Single Pilot IFR - Data is needed to provide trade-off criteria to evaluate the interdependence of a range of stability and control augmentation systems and display systems, for both dual and single pilot IFR operations. Several NASA/FAA simulator tests have been conducted and a series of flight tests were recently completed to verify the ground based simulator data. This work will continue.

Simulator Requirements - A serious look is being given toward the use of simulators to reduce the flight time required for type certification. It was suggested that NASA could make a major contribution in this area because of the extensive facilities and background which have been developed. The actions needed include a data base on math modeling and math model fidelity. A cookbook of fidelity requirements was proposed that documents the fidelity requirement as a function of specific certification task items. Information on procedures for validation of simulators used for certification studies is also needed. Some work in these areas has been initiated and an expansion of this effort is being considered.

Software Verification and Validation for Digital Systems - Digital systems technology is advancing at an extremely rapid pace. With the incorporation of advanced digital systems in helicopters for control and guidance functions, methods and criteria for the certification of these systems are needed. NASA is assisting the FAA in this area by sponsoring and performing analyses and conducting laboratory investigations in order to evaluate and improve verification and validation techniques. This research will continue and will grow.

Optimum Take-Off Techniques

This need deals with optimizing take-off techniques so that maximum margins are realized in the event of engine failure for multi-engine helicopters and also deals with minimum field length requirements. The technology required is accurate vehicle performance information. The required action is to develop control/display systems which allow for the full use of the performance which is available in a given situation. It also involves flight testing to investigate techniques for determining and optimizing performance as a function of sideslip, ground effect, engine and control systems response, etc. There is a limited amount of activity in this area. A series of flight tests using a CH-47 to study the effect of sideslip on performance is in progress. Further work including control in engine-out situations and in autorotation is planned.

Heavy-Lift/Multi-Lift

This user need requires advanced control systems technology including heavy-lift control techniques, control algorithms, system concepts, etc. The workshop participants advised a "fresh look" at the whole situation including load stabilization during the ferry portion of the mission and precise load placement at the job site. The NASA program at this time involves primarily analyses and simulation of the heavy-lift problem. This could result in flight tests using the CH-47.

Multi-lift involves lifting large and heavy loads with several helicopters (two or more). One concept for this control problem would be a master/slave concept where one vehicle is used as the master and the other vehicle(s) control system(s) would be automatically slaved to the master. Advanced control systems technology work has been initiated on this problem, using a concept called TAFCOS, Total Automatic Flight Control System.

Flying/Ride Qualities

Productive and safe helicopter operation is linked to pilot workload and fatigue for normal operations, and manageable workload under emergency situations. Active control concepts can provide improved flying and ride qualities for normal operation, and improve the safety of an emergency situation. There were several experiments specifically proposed for NASA by one of the manufacturers, and it was suggested that the Vertical Motion Simulator could be used for this type of work because of its unique large motion capabilities. The experiments proposed for the emergency situations include engine failure transients management, automatic water ditching capabilities under emergency IFR/night conditions, and tail rotor malfunction. Automatic sensing of tail rotor drive failures could allow the tail rotor to be put into autorotation and thereby maintain control. NASA work will be considered in these areas. Active control concept studies proposed for normal operations included relaxed static stability, gust alleviation, reduction/elimination of cross coupling effects including propulsion/flight controls, and vibration suppression. Relaxed longitudinal stability involves horizontal tail size reduction, which reduces weight and cost and improves performance. NASA work in some of these areas is ongoing and others could be included in a planned NASA New Initiative in 1983.

Another R&D proposed action was to develop criteria for optimum feel for force-gradient type controllers and to develop concepts for pilot/copilot coordination using side arm force sticks. A joint NASA/Army research task in this area is currently in progress.

Operational Reliability

The users at this workshop spoke repeatedly of the need for improved reliability and redundancy of the helicopter systems, including avionics systems. The items mentioned included improved connectors, improved cabling, more reliable sensors and displays, etc. R&D work in this area includes analysis, laboratory, and some flight investigations covering such items as hardened system design, tolerance to lightning and electromagnetic interference (EMI), and advanced systems architecture. Work in these areas is going on in the industry. NASA's work tends to be oriented toward new concepts and advanced systems. Industry is best suited to develop improved connectors and cabling, and hardware for harsh environments such as extreme cold, high vibration, and electromagnetic interference, lightning, etc. There is ongoing work by DOD and NASA on lightning and EMI protection for aircraft avionics. This work will continue since there is major concern over the proper design of fly-by-wire and digital systems for lightning and EMI protection.

Low Altitude Turbulence & Velocity Profiles

The turbulent wake shed by large structures and buildings and air flow shears caused by buildings can be hazardous to helicopter operations in their vicinity. There is no new technology required but it was suggested that the data base could be expanded. The action suggested is to perform small scale wind tunnel tests of model structures. Small scale data should then be verified by a limited set of full-scale measurements of turbulence and velocity profiles in the vicinity of offshore oil rigs, building rooftops, and large buildings and combinations of buildings. NASA had done some work in this area in the past. Some small scale wind tunnel work is in progress.

ALL WEATHER OPERATIONS

Several users identified the need for greater IFR and bad-weather capabilities, and for increased use of night operations. User needs are summarized for four categories: Remote Area Operations, Terminal Area Operations, Certification Criteria, and IFR Low Speed and Hover.

Remote Area Operations

The technology requirements for this category include such items as accurate low altitude navigation, reliable communications, obstacle avoidance and unimproved landing site operations.

Accurate Low Altitude Navigation - Systems such as LORAN, Decca, and VLF Omega are now in use. Technology is being developed for low altitude operations at remote sites using the Global Positioning System (GPS) concept, based on the NAVSTAR Satellite system. This system should be fully operational in 1987 and offers a potential for helicopters to navigate anywhere in the world with continuous 24-hour coverage. Using low cost receiver sets, it will provide the capability for non-precision approach at remote sites. NASA was urged to work on furthering the civilian rotorcraft use of this concept. A specific area identified was differential GPS, where a ground set is placed on a known location and used to reduce system errors, thereby furthering improving performance to perhaps provide precision approach capabilities. NASA GPS investigations are already underway using a loaned USAF GPS Z-set, with specific plans to work on the differential GPS concept. These investigations are to be coordinated with the FAA. An FAA representative suggested that perhaps NASA could assist FAA in the development of a low-cost GPS receiver set.

Reliable Communications - In order to improve control and safety at remote sites where light-of-sight communication is not feasible, there is an urgent need for reliable communications between aircraft and air traffic controllers and other aircraft and landing sites. Satellite relay communication technology is here today and this needs to be developed further. No known NASA work is underway in this area. However the FAATC has current activity in this area.

Obstacle Avoidance - Obstacle strikes by helicopters, especially wire strikes, are a very real problem. Visual markings of wires for day VFR has been of some help but much additional work is needed to protect the operators in all-weather situations and for night operations. The solution for the obstacle clearance problem in terminal areas without approach aids appears to be the use of multi-spectral imaging techniques including such things as infrared, high resolution radar, and image enhancement techniques. Development of pictoral displays of known hazards plus automated alerting to known and sensed obstacles would greatly aid the pilot. The military have done extensive work in the infrared technology area and civil applications should be developed. NASA plans to investigate several concepts including millimeter wave length radar and high resolution radar using antennae imbedded in the rotor blades. Radar image enhancement and ground clutter elimination investigations are currently being sponsored by NASA.

Unimproved Landing Site Operations - The industry needs the ability to operate rotorcraft to remote, unimproved landing sites, not only under VFR conditions, but also under marginal VFR or IFR conditions. This is especially true for emergency or rescue operations, but such capability also improves vehicle utilization and productivity for normal operations. The amount of improvement depends upon the site and its climatic characteristics. Work in this area includes airborne radar approach systems and techniques to reduce pilot workload and enhance safety, development of low cost portable MLS, the use of Loran-C, and further downstream, the use of GPS. Airborne radar appraoch overwater has been shown to be quite feasible, although it is a high pilot workload task and problems related to false target identification need to be worked out. Solutions include automated radar operation, improved guidance combined with radar display, the use of beacons, and/or image enhancement techniques. Airborne radar approach overland studies have indicated a major breakthrough in elimination of ground clutter. Preliminary results of the use of special low-cost ground-based radar reflectors combined with onboard computers show great promise for presenting very accurate, usable radar return information on the location of landing sites relative to the aircraft. (This system would also have value at regular airports and for conventional aircraft as an independent landing monitor.) This work is continuing.

Terminal Area Operations

The technology requirements for this category include integration with ATC, noise reduction, and low-cost integrated avionics.

Integration with ATC - Technology needs involve evaluations of 3D, 4D, and RNAV concepts to enable greater freedom in use of airspace, time controlled arrival at initial and final approach fixes in a terminal area, and non-interference operation with conventional aircraft traffic into busy terminals. NASA simulation and flight investigations are ongoing and will continue, and are being done jointly with the FAA. Research includes ATC simulations wherein cockpit display of traffic information is evaluated using piloted simulation.

Noise Reduction - This topic is concerned with minimizing the noise impact on the community by developing operational flight profiles and guidance that confine the noise footprint to less sensitive regions of the terminal area. This work is ongoing.

Low-Cost Integrated Avionics - Avionics which provide for advanced operational concepts, including Category III all-weather capability, currently require complex and sophisticated systems. There is a need to develop the technology required for implementing advanced operational capabilities onboard the helicopter in a simple, low cost manner so as to be affordable to the civil operator. Work is in progress in this area.

Certification Criteria

The technology requirement is a data base and criteria which can be used by the FAA to set IFR operational requirements. Recent NASA investigations in collaboration with FAA have included TERPS criteria for airborne radar approaches to offshore oil rigs and TERPS criteria for Microwave Landing System (MLS) approaches for helicopter type operations. The wide airspace coverage provided by MLS may be used to provide separation of helicopter and fixed-wing IFR traffic, and improved obstacle clearance and noise abatement procedures. NASA was encouraged at this workshop to continue this assistance to the FAA, and especially in the area of defining certification criteria specific to rotorcraft to enable them to be treated as different vehicles from fixed wing aircraft. NASA was urged to work specifically with the FAA Southwest Region as it is the lead region with respect to helicopters.

IFR Low Speed and Hover

The technology requirement is for accurate vehicle position and velocity information near hover. A typical problem area which was cited in this workshop was the case of arctic white-out situations where visual reference is lost during the critical hover and touchdown phase of operation. Research and development of sensors and displays is required. NASA was urged to work on low air speed sensors to provide accurate low air speed data. Present pitot static systems near the fuselage are influenced by the rotor flow field and are therefore unreliable at low speed and during hover. Also, there is a need for a sensor capable of detecting the aircraft position relative to the ground at the hover and landing site. There is also a need for displays that provide for intuitive control commands. NASA is gaining experience with several low airspeed sensor systems and has initiated development of a laser low airspeed sensor for research applications. Advanced displays for use in hover are also under investigation.

HUMAN FACTORS

The statement was made by one manufacturer that two thirds of all helicopter accidents list pilot error as a cause or contributing factor. The list of potential areas for reducing pilot error include improved aircraft design, improved air traffic control and pilot interface and improved flight deck discipline. In general, the need is to reduce pilot workload and fatigue. The general technology requirement is advanced cockpit design. It was pointed out that the helicopter came after fixed wing aircraft, and that current helicopter flight deck design reflects an adaptation of fixed wing cockpit design. Specific proposed R&D actions were as follows:

(1) Develop system functions so as to allow the pilot to act as a systems manager rather than just as a controller. NASA work in this area is in progress.

(2) Develop integrated controller so as to free up the other hand for other tasks. Industry and joint Army/NASA work is in progress.

(3) Coordinate with government, civil, foreign agencies in the development of standardized displays and controls. No NASA activity is planned at this time.

(4) Develop cockpit configurations which provide an increased field of view. This could include items like sidearm controllers, audio/visual/tactile pilot information options, etc. NASA and the Army have ongoing related work and plan growth in this research area.

MISCELLANEOUS COMMENTS

Some participants noted that while the dialogue between NASA and rotorcraft manufacturers appeared to be relatively good, the dialogue with the "second level" industries, such as the avionics and instrumentation industry could be improved. This could include reviews of NASA programs and related industry research on an annual or semi-annual basis. The observation was made that some long term NASA programs could be passed up by the pace of new technology. Increased dialogue would minimize this problem.

One manufacturer recommended that NASA acquire a modern twin engine helicopter for research where control power and rotor dynamics are important. Modern rotor systems are required for controls-related research in the higher frequency domain, and twin engine altitude/velocity limitations should be factored into terminal guidance solutions.

Helicopter icing was identified as a significant All-Weather Rotorcraft problem needing technology development. This was considered to be a topic of greater relevance to the Aerodynamics and Propulsion Subsessions. With regard to possible Avionics and Flight Controls technology efforts aimed at the icing problem, it was suggested that improved ice detection systems would be of value.

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TABLE I

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA FLIGHT CONTROLS AND AVIONICS SUB-AREA FLIGHT DYNAMICS & CONTROLS

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
* Certification Criteria	* Stability Requirements	In progress	* Develop Data Base
	* Dual/Single Pilot IFR	In Progress	* Simulation and Flight Investigations with FAA
	* Simulator Requirements	In Progress	* Develop Reference Material - Math Modeling - Validation Procedures - Fidelity Requirements Cookbook
	* Software Verification & Validation for Digital Systems	In Progress	* Perform Analysis and Laboratory Investigations * Develop Tools & Techniques * Coordinate with FAA
* Optimum Take-Off Techniques	* Accurate Vehicle Performance Information	In Progress	* Develop Control/Display Systems Which Allow Full Use of Available Performance
		In Progress	* Develop Flight Test Techniques for Determination of Performance - F(β, G.E., Control & Engine Response)
* Heavy Lift/Multi-Lift	* Advanced Control Systems	Planned	* Develop New Concepts for Ferrying and Load Placement
		Initiated	* Develop Multi-Aircraft Control Techniques- (e.g. Master/Slave)
* Flying/Ride Qualities	* Advanced Control Systems	Planned	* Develop Active Control Concepts - 1) For Emergency Situations - Engine Failure Transients - Automatic IFR/Night Ditching - Tail Rotor Malfunctions

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA FLIGHT CONTROLS AND AVIONICS SUB-AREA FLIGHT DYNAMICS & CONTROLS

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
		Planned (Some in Progress)	2) For Improved Handling - Relaxed Static Stability - Gust Alleviation - Remove Cross Coupling-Including Propulsion/Flight Control - Vibration Suppression
		In Progress	* Investigate with Army multi-axis Force Gradient Controller
* Operational Reliability	* Improved Avionic Systems	In Progress	* Perform Analysis & Laboratory Investigations - Advanced Architecture - Software V&V - Hardened System Design - Lightning/EMI Tolerance
* Low Altitude Turbulence Velocity Profiles	* Existing	Some Past Work (None for Oil Rigs)	* Measure Turbulence & Velocity Profiles - Offshore Oil Rigs - Rooftops - Large Buildings
		In Progress	* Perform Small Scale Wind Tunnel Tests of Model Structures

COMMENT: NASA should acquire a modern twin engine helicopter for research in which control power and rotor dynamics play a part. Modern rotor systems are required for work in the frequency domain in which automatic control systems operate, and twin engine h/v limitations should be factored into terminal guidance solutions.

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA FLIGHT CONTROLS AND AVIONICS SUB-AREA All Weather

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
* Remote Area Operation	* Accurate Low Altitude Navigation	Initiated	* Develop GPS for Rotorcraft Needs - Set Architecture & Interfaces - Differential GPS
	* Reliable Communi-- cations	None	* Work with FAA to Develop Satellite Voice Links
	* Obstacle Avoidance	In Progress	* Develop Multi-Spectral Imaging Techniques - IR, Radar, Pictorial Displays, Image Enhancement
	* Unimproved Landing Site Operations	In Progress	* Develop Approach Capability Using Airborne Radar, GPS, Loran, Low Cost Portable MLS
* Terminal Area Operations	* Integration with ATC	In Progress	* Simulation and Flight Evaluations - 3D/4D RNAV - Non-Interference with Conventional Traffic
		In Progress	* Develop- with FAA Data Links as Alternative to Voice Communication
	* Noise Reduction	In Progress	* Develop Operational Flight Profiles to Confine Noise Footprint.
	* Low-Cost Integrated Avionics	In Progress	* Develop and Demonstrate an Advanced Low Cost, Integrated Category III Avionics System for Civil Helicopters

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA FLIGHT CONTROLS AND AVIONICS SUB-AREA All Weather

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
* Certification Criteria	* Operational Criteria	In Progress	* Assist FAA in Defining IFR Criteria-TERPS, etc.
* IFR Low Speed and Hover	* Accurate Vehicle Position & Velocity Information	In Progress	* Develop Accurate Low Airspeed Sensor
		In Progress	* Display Development
		In Progress	* Low Cost Attitude & Heading Reference System

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA FLIGHT CONTROLS AND AVIONICS SUB-AREA HUMAN FACTORS

USER NEED	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
* Reduced Pilot Workload	* Advanced Cockpit Design	In Progress	* Develop System Functions to Allow Pilot to Act as Manager.
		In Progress	* Develop Integrated Controller
		None	* Coordinate with Government, Civil, Foreign Agencies in Development of Standardized Displays and Controls
		In Progress	* Develop Cockpit Configurations with Maximum Field of View - (Sidearm Controllers, Audio/Visual/Tactile Pilot Information Options).

VOLUME IV

APPENDIX A

NASA PROGRAM PRESENTATIONS

* EXECUTIVE SUMMARY OF ROTORCRAFT PROGRAMS IN FLIGHT CONTROL, AVIONICS, AND HUMAN FACTORS
* NASA HELICOPTER FLIGHT CONTROL RESEARCH - ROBERT CHEN
* NASA ALL-WEATHER ROTORCRAFT PROGRAM - JOHN BULL
* NASA HELICOPTER MAN-SYSTEM INTEGRATION (HUMAN FACTORS) - ED HUFF

NASA

EXECUTIVE SUMMARY OF ROTORCRAFT PROGRAMS
IN
FLIGHT CONTROL, AVIONICS, AND HUMAN FACTORS

BRIEF NARRATIVES

* Major Task
* Description
* Contacts
* RTOP
* Publications

EXECUTIVE SUMMARY OF ROTORCRAFT PROGRAMS
(Narrative)

FLIGHT DYNAMICS, CONTROLS, AND AVIONICS

MAJOR TASK	DESCRIPTION	CONTACTS/RTOP
HELICOPTER FLIGHT DYNAMICS		
1. Flying Qualities Data Base and Design Criteria (Ongoing Program)	This ongoing research task is to develop basic handling qualities data base and design criteria for flight control/display systems for low level military missions. The task is also to establish data for revision of airworthiness standards for IFR operation.	J. A. Franklin Flight Dynamics and Controls Branch, Ames Research Center, 965-5009/505-42-21
2. Advanced Control/Display Research (Ongoing Program)	This task, which is scheduled to begin in the current fiscal year, has three specific subtasks: (1) development of control/display concepts for engine out operation; (2) development of concepts for external load operations under IMC/VMC; and (3) in-house research support for ADOCS cockpit controls/AFCS.	J. A. Franklin Flight Dynamics and Controls Branch, Ames Research Center, 965-5009/505-42-21
3. Analytical Support (Ongoing Program)	This task covers three elements: (1) parameter identification; (2) real-time simulation math model improvements; and (3) software development for analysis and optimization. The objectives of these research elements are to effectively support the flying qualities research, both ground-based and in-flight, to provide analytical tools for flight control analysis and synthesis, and to interpret unexplained flight dynamic phenomena.	J. A. Franklin Flight Dynamics and Controls Branch, Ames Research Center, 965-5009/505-42-21

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Publications in Helicopter Flight Dynamics

NASA Reports

1. Peter D. Talbot and Lloyd D. Corliss: A Mathematical Force and Moment Model of a UH-1H Helicopter for Flight Dynamics Simulation. NASA TM-73254, June 1977.

2. Lloyd D. Corliss and Peter D. Talbot: A Failure Effects Simulation of a Low Authority Flight Control Augmentation System on a UH-1H Helicopter. NASA TM 73258, August 1977.

3. Robert T. N. Chen, et al: A Piloted Simulator Study on Augmentation Systems to Improve Helicopter Flying Qualities in Terrain Flight. NASA TM 78571, March 1979.

4. J. Victor Lebacqz: Survey of Helicopter Control/Display Investigations for Instrument Decelerating Approach. NASA TM 78565, March 1979.

5. John M. Davis: Instrumentation Calibration Manual for UH-1H Helicopter with V/STOLAND System. NASA TM 78568, April 1979.

6. Robert T. N. Chen: A Simplified Rotor System Mathematical Model for Piloted Flight Dynamics Simulation. NASA TM 78575, May 1979.

7. Robert T. N. Chen: Effects of Primary Rotor Parameters on Flapping Dynamics. NASA TP 1431, January 1980.

8. Fredric A. Baker, et al: V/STOLAND Avionics System Flight - Test Data on a UH-1H Helicopter. NASA TM 78591.

9. Edwin W. Aiken: A Mathematical Representation of an Advanced Helicopter for Piloted Simulator Investigations of Control System and Display Variations. NASA TM 81203, July 1980.

10. Ronald M. Gerdes: A Pilot's Assessment of Helicopter Handling-Qualities Factors Common to Both Agility and Instrument Flying Tasks. NASA TM 81217, July 1980.

11. Peter D. Talbot, et al: Effects of Rotor Parameter Variations on Handling Qualities of Unaugmented Helicopters in Simulated Terrain Flight. NASA TM 81190, August 1980.

12. J. Victor Lebacqz, et al: A Piloted Simulator Investigation of Static Stability and Stability/Control Augmentation Effects on Helicopter Handling Qualities for Instrument Approach. NASA TM 81188/FAA-RD-80-64, September 1980.

13. Robert T. N. Chen, et al: Kinematic Properties of the Helicopter in Coordinated Turns. NASA TP 1773 (1981).

Papers

1. Robert T. N. Chen and Peter D. Talbot: An Exploratory Investigation of the Effects of Large Variations in Rotor System Dynamics Design Parameters on Helicopter Handling Characteristics in Nap-of-the-Earth Flight. AHS Preprint 77-34-41 May 1977, also J. AHS July 1978.

2. Robert T. N. Chen, et al: A Piloted Simulator Investigation of Augmentation Systems to Improve Helicopter Nap-of-the-Earth Handling Qualities. AHS Preprint No. 78-20, May 1978.

3. K. Miyajima: Analytical Design of a High Performance Stability and Control Augmentation System for a Hingeless Rotor Helicopter. ASH Preprint No. 78.27, May 1978.

4. Raymond D. Forrest, et al: Piloted Simulator Investigation of Helicopter Control Systems Effects on Handling Qualities During Instrument Flight. AHS Preprint No. 79-26, May 1979.

5. J. Victor Lebacqz: A Review of Helicopter Control-Display Requirements for Decelerating Instrument Approach. Paper presented at AIAA AFM Conference, August 1979.

6. Edwin W. Aiken: The Effects of Control System and Display Variations for an Attack Helicopter Mission Through Piloted Simulation. Paper presneted at 1980 Army Science Conference, June 1980.

7. Edwin W. Aiken and Lt. Col. Robert K. Merrill: Results of a Simulator Investigation of Control System and Display Variations for an Attack Helicopter Mission. AHS Preprint No. 80-28, 1980.

8. J. Victor Lebacqz and Raymond D. Forrest: A Piloted Simulator Investigation of Static Stability and Stability/Control Augmentation Effects on Helicopter Handling Qualities for Instrument Approach. AHS Preprint No. 80-30, May 1980.

9. Robert T. N. Chen: Selection of Some Rotor Parameters to Reduce Pitch-Roll Coupling of Helicopter Flight Dynamics. Paper presented at National Specialists' Meeting on Rotor System Design, AHS Preprint No. I-6, Oct. 1980.

EXECUTIVE SUMMARY OF ROTORCRAFT PROGRAMS
(Narrative)

FLIGHT DYNAMICS, CONTROLS, AND AVIONICS

MAJOR TASKS	DESCRIPTION	CONTACTS/RTOP
FLIGHT CONTROL AND AVIONICS		
1. Total Automatic Flight Control System Development (TAFCOS) (Ongoing Program)	This ongoing research task is to develop advanced flight control system concepts and algorithms which effectively integrate airframe, propulsion and subsystem control functions to enhance the performance, economics, and safety of future rotorcraft. The methodology will be verified first by in-flight testing with the UH-1H and later extended to a tilt rotor aircraft.	G. Meyer, Flight Dynamics and Controls Branch, Ames Research Center, 965-5444/505-42-31
2. Fault Tolerant Implementation of TAFCOS (Ongoing Program)	The objective of this task is to develop advanced concepts and means of mechanization to achieve fault-tolerant computation, data communication and actuation in implementing the TAFCOS described above for the rotorcraft.	D. Brocker, Systems Integration Branch, Ames Research Center, 965-5326/505-42-31
3. Application of TAFCOS to Development of Multi-Lift Concepts (Ongoing Program)	This task, which is just being initiated is to develop control concepts to increase the operational capability of multi-lift. Greatly reduced pilot workload is required when multiple helicopters are used simultaneously to lift a single heavy external load. Promising twin and multi-lift control systems configurations will be developed and evaluated in simulation and in-flight.	G. Meyer, Flight Dynamics and Controls Branch, Ames Research Center, 965-5444/532-06-11

EXECUTIVE SUMMARY OF ROTORCRAFT PROGRAMS
(Narrative)

FLIGHT DYNAMICS, CONTROLS, AND AVIONICS

MAJOR TASKS	DESCRIPTION	CONTACTS/RTOP
FLIGHT CONTROL AND AVIONICS		
4. Active Control Systems Technology (Proposed new initiative in FY 83)	The objective of this task is to develop fault tolerant systems architecture concepts to achieve required levels of reliability in full authority digital fly-by-wire/light active control systems. Subsystems technology, including redundant distributed computation network, actuators and data communication will be developed. Methods of verification and validation of digital systems will also be developed/evaluated. Control modes described in task 5 that provide enhanced mission capability will be integrated with the primary flight controls in the overall system architecture. Flight evaluation of promising system concepts will be conducted.	D. Brocker, Systems Integration Branch, Ames Research Center, 965-5376
5. Active Control Applications (Proposed new initiative in FY 83)	This task comprises development of active control systems for gust alleviation envelope limiting, active empennage control, and integrated flight and propulsion controls. Improvement in ride comfort will be achieved through alleviation of gust response. Full utilization of the flight envelope and prevention of the helicopter from entering conditions of loss of aircraft controls will be provided by envelope limiting control systems. Full benefits will be explored through combined active controls for the empennage and the main rotor. Appropriately integrated flight and propulsion control systems will be developed to avoid adverse dynamic coupling and enhance maneuver capabilities.	J. A. Franklin, Flight Dynamics and Controls Branch, Ames Research Center, 965-5009

Publications Related to TAFCOS

Reports

1. George Meyer and Luigi Cicolani: A Formal Structure for Advanced Automatic Flight Control Systems, NASA TN D-7940, 1975.

2. Luigi Cocilani and Stein Weissenberger: A Nonlinear Command Generator for a Digital Flight Control System. NASA TP-1221, 1978.

3. Luigi Cicolani; B. Sridhar, and George Meyer: Configuration Management and Automatic Control of an Augmentor Wing Aircraft with Vectored Thrust. NASA TP-1222, 1979.

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5. Wehrend, William R., Jr.; and George Meyer: Flight Tests of the Total Automatic Flight Control System (TAFCOS) Concept on a DHC-6 Twin Otter Aircraft. NASA TP-1513, 1980.

6. G. Allan Smith and George Meyer: Application of the Concept of Dynamic Trim Control to Automatic Landing of Carrier Aircraft. NASA TP-1512, 1980.

7. George Meyer and Luigi Cicolani: Application of Nonlinear Systems Inverses to Automatic Flight Control Design System Concepts and Flight Evaluation, 1980 AGARDOGRAPH on Theory and Applications of Optimal Control in Aerospace Systems. P. Kant Ed.

8. W. Dunn, J. Johnston and G. Meyer: Ramp - A Fault Tolerant Distributed Microcomputer Structure for Aircraft Navigation and Control. 14th Asilomar Conference on Circuits, Systems and Computers, Pacific Grove, Nov. 1980.

9. M. Zanger: Intercommunications in Real Time, Redundant, Distributed Computing System. Joint Research Interchange NCA0)R625-001, Final Report Aug. 1980.

Papers

1. G. Allan Smith and George Meyer: Total Aircraft Flight Control System Balanced Opne- and Closed-Loop Control with Dynamic Trimmaps. 3rd Avionics Conference, Dallas, 1979.

2. George Meyer: Nonlinear System Inverses, Workshop on the Mathematical Theory of Networks and Systems, Virginia Beach, May 1980.

3. George Meyer: Use of System Inverses in the Design of Flight Control Systems for Aircraft with Nonlinear Characteristics, 1980 Joint Automatic Control Conference San Francisco, Aug. 1980.

NASA ALL-WEATHER ROTORCRAFT PROGRAM

MAJOR TASKS	DESCRIPTION	CONTRACTS/RTOP
1. Airborne Radar Approaches	Flight tests have been conducted (Bell 212, SH-3A) and simulations and flight tests are planned (SH-3G) to develop Airborne Radar as an "onboard" navigation system for IMC operations into remote sites where few ground navigation facilities are available. Objectives include development of instrument procedures to offshore oil rigs, experimental concepts for detecting radar reflectors in ground clutter, and flight director guidance information superimposed on the radar display. Joint NASA/FAA tests have been conducted to aid the development of TERPS criteria.	J. Bull/Aircraft G&N Br/ARC/5425 532-01-11, 532-06-11
2. Multi-Spectral Imaging Systems	Lab tests, simulations, and flight tests (SH-3G) are planned to investigate multi-spectral systems for high resolution imaging displays. Objective is to combine imaging sensors operating at various frequencies to obtain best combination of display resolution versus weather penetration during an IMC approach.	J. Bull/Aircraft G&N Br/ARC/5425 532-01-11, 532-06-11
3. Navstar Global Positioning System (GPS)	Lab tests are being conducted using a GPS Z-Set receiver and simulations and flight tests (SH-3G) are planned to investigate suitability of Navstar for the civil helicopter mission. Objective is to develop and evaluate concepts such as "differential" GPS, which will sufficiently enhance the navigation performance of low cost GPS receivers so that helicopter IFR landing approaches can be conducted.	J. Bull/Aircraft G&N Br/ARC/5425 532-01-11, 532-06-11

MAJOR TASKS	DESCRIPTION	CONTRACTS/RTOP
4. Microwave Landing System (MLS) Precision Approaches	Analysis, simulations, and helicopter flight tests (UH-1H) are ongoing to investigate IMC precision approach capability when using a Micro Wave Landing System. The wide airspace coverage provided by MLS may be used to provide separation of helicopter and fixed-wing IFR traffic, and improved obstacle clearance and noise abatement procedures. Joint NASA/FAA flight tests have been conducted to aid the development of TERPS criteria.	J. Bull/Aircraft G&N Br/ARC/5425 532-01-11, 532-06-11
5. 3D/4D Optimal Guidance, ATC Interface	Analysis and simulations, are ongoing to develop optimal flight paths for minimizing fuel consumption and ground noise and to investigate implementation of optimal flight paths in the ATC environment, Research includes ATC simulations wherein Cockpit Display of Traffic Information is evaluated using piloted simultion. These ATC simulations are conducted jointly with the FAA.	H. Erzberger/Aircraft G&N Br/ARC/5450 532-06-11
6. Low Cost Integrated Cat III Avionics	Research objective is to develop a Low Cost Integrated Category III Avionics System for civil helicopter missions. Advanced operational concepts developed in other all-weather program elements will be integrated into a single avionics system; designed, fabricated, and demonstrated in flight tests. Avionics design objectives are reliability, cost effective system architecture, and integrated pilot controls and displays. Technology developed in NASA's General Aviation Advanced Avionics Program will be adapted to this rotorcraft system.	D. Denery/Aircraft G&N Br/ARC/5438 532-06-11

NASA ALL-WEATHER ROTORCRAFT PROGRAM

MAJOR TASKS	DESCRIPTION	CONTRACTS/RTOP
7. Advanced Navigation and Display Concepts	Analysis, simulations, and flight tests (UH-1H) are ongoing to investigate advanced navigation and display concepts. Research areas include display design through analytical pilot models, performance comparison of complementary and Kalman filter mechanizations, and development of a "hybrid" low cost inertial system.	G. Xenakis/Aircraft G&N Br/ARC/5430 532-01-11
8. Autoland Helical Approaches	Flight tests are being conducted (UH-1H) to develop and evaluate automatic helical IMC approaches. Helical approaches have been flown "hands off" to hover and touchdown. Navigation, guidance, and display requirements are being defined to provide capability for helical approach paths in the terminal area which will minimize approach airspace requirements and provide separation from fixed-wing traffic.	G. Xenakis/Aircraft G&N Br/ARC/5430 532-01-11
9. hipboard NAVTOLAND Systems	Simulations are being conducted (Harrier, SH-2F) and flight tests are planned (SH-3G) in support of the Navy's Navtolan d program. Objective of the program is to develop and evaluate an integrated flight control and display system for landing VTOL aircraft and helicopters on ships in sea-state 5 (12 ft waves).	G. Xenakis/Aircraft G&N Br/ARC/5430 532-05-11

HELICOPTER HUMAN FACTORS

Major Tasks	Descriptions	Contacts (RTOP 505-42-41)
1. Displays and Controls for Helicopter Applications	Investigations are being conducted of pilot system interface technologies which will allow the pilot to perform helicopter missions with reduced workload and improved safety. The objectives are to explore experimentally the ulitity of advanced visual displays, synthetic voice, continuous auditory displays, automatic speech recognition and integrated controllers.	W. Wright, ARC J. Stevenson, ARC C. Coler, ARC J. Hartzell
2. Helicopter Pilot Workload and Performance Assessment	A team effort is being initiated to develop a standard pilot workload and performance measurement system. Work involves the identification of flight scenarios reflecting the full range of pilot activities; development of a pilot model with parameters identified with flight scenario components; and development of a measurement set including subjective ratings, secondary tasks and physiological indices.	E. Huff, ARC J. Hartzell, ARC R. Remington, ARC J. Voorhees, ARC
3. Advanced Helicopter Crew Station Design	Investigations are planned in FY-82 to explore the manner in which new interface technology can best be integrated into an advanced helicopter cockpit. Objectives are to establish design criteria for visual, auditory and tactile displays, and to synthesize crew station concepts that improve mission effectiveness, safety and ease of operation.	J. Hemingway, ARC J. Voorhees, ARC

NASA HELICOPTER FLIGHT CONTROL RESEARCH

- FLIGHT DYNAMICS
- FLIGHT CONTROLS AND AVIONICS

AMES RESEARCH CENTER

R. T. N. CHEN

HELICOPTER FLIGHT DYNAMICS

TASK 1: FLYING QUALITIES DATA BASE AND DESIGN CRITERIA

TASK 2: ADVANCED CONTROL/DISPLAY RESEARCH

TASK 3: ANALYTICAL SUPPORT

TASK 1

FLYING QUALITIES DATA BASE AND DESIGN CRITERIA

OBJECTIVES

NOE FLYING QUALITIES (NASA-ARMY)

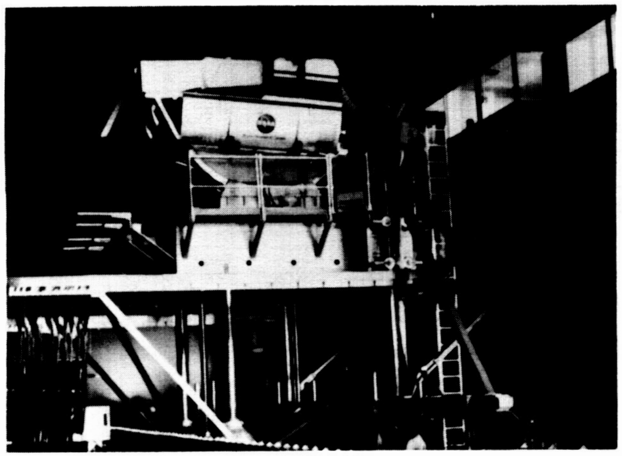
- DETERMINE EFFECTS OF DESIGN PARAMETERS ON NOE FLYING QUALITIES
- DEVELOP SCAS AND DISPLAY CONCEPTS TO IMPROVE NOE FLYING QUALITIES IN VMC AND IMC/NIGHT
- AUGMENT DATA BASE TO UPDATE MIL 8501 A

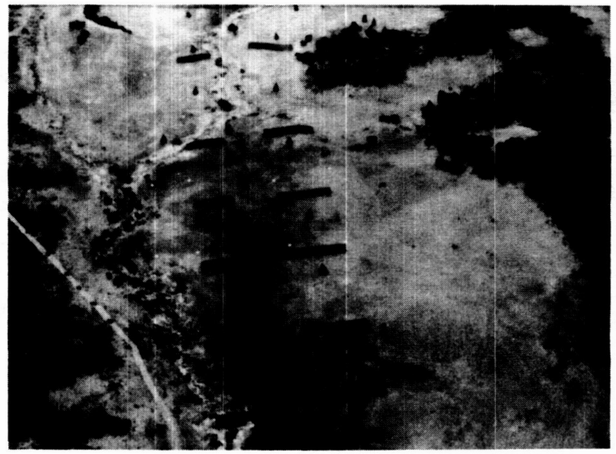
IFR CERTIFICATION CRITERIA (NASA-FAA)

- OBTAIN DATA TO ASCERTAIN/ SUBSTANTIATE EXISTING OR PROPOSED CERTIFICATION CRITERIA
- OBTAIN DATA TO PROVIDE IFR DESIGN GUIDELINES

NOE FLYING QUALITIES RESEARCH APPROACH

- <u>ANALYSIS</u>
- PILOTED GROUND-BASE SIMULATION





- FLIGHT VERIFICATION

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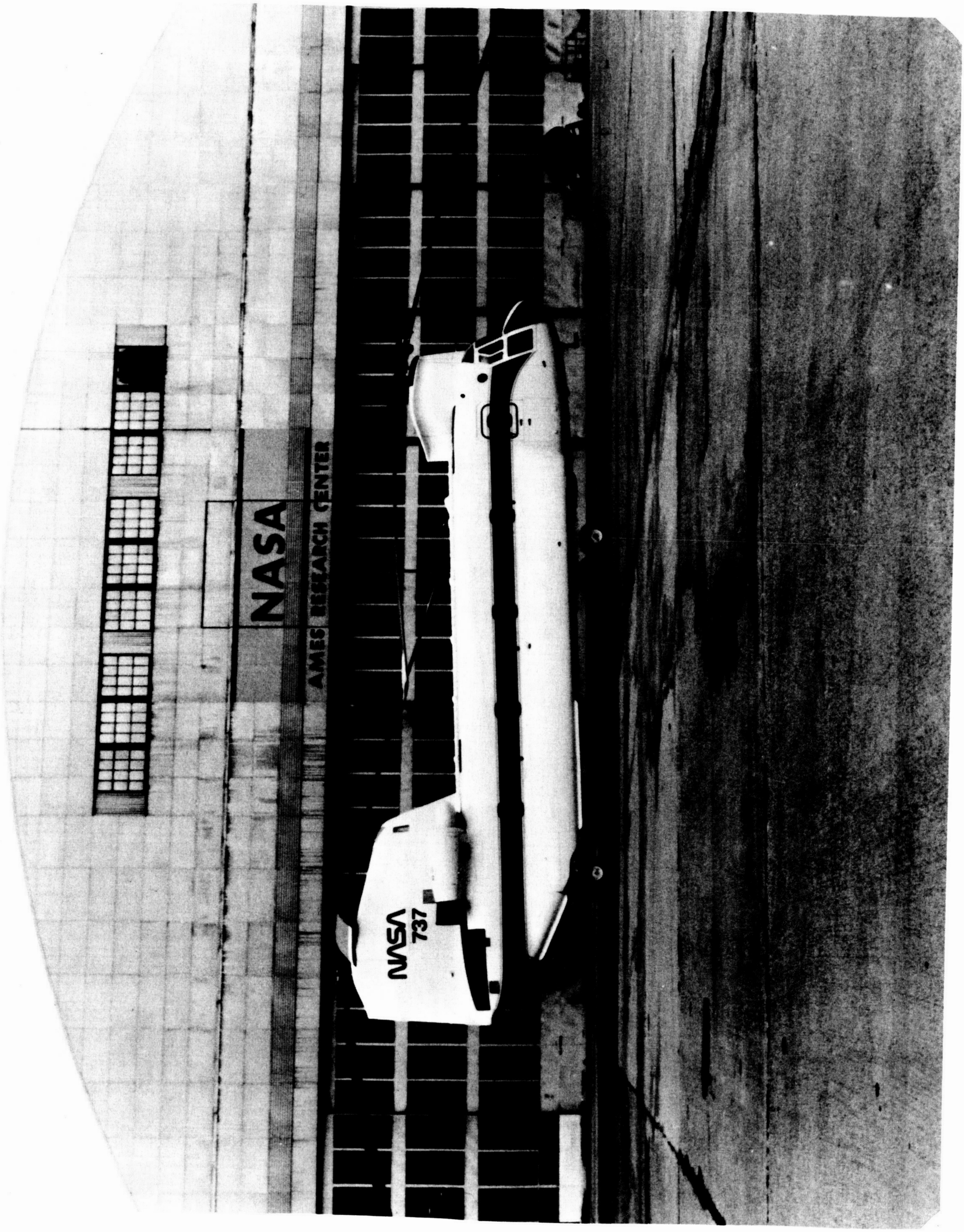

TASK 1 STATUS

- NOE FLYING QUALITIES RESEARCH

ACCOMPLISHMENT

SIMULATION

- EFFECTS OF ROTOR DESIGN PARAMETERS & SCAS
- CONTROL/DISPLAY TRADE OFF FOR ATTACK MISSION
- TWO-AXES SIDEARM CONTROLLER
- A^2H BACK UP SYSTEM ENGAGEMENT TRANSIENT

FLIGHT

- DATA OBTAINED FROM VARIABLE STABILITY UH-1H
  - PITCH-ROLL COUPLING
  - ROLL DAMPING vs SENSITIVITY
  - EFFECT OF LIMITED FIELD OF VIEW

PROJECTS IN PROGRESS (FY 81-82)

- EFFECTS OF ENGINE DYNAMICS
- CONTROL POWER REQUIREMENTS
- 4-AXES SIDE ARM CONTROLLER

- FLIGHT VERIFICATION OF GROUND-BASED SIMULATION USING UH-1H
  - COLLECTIVE-PITCH COUPLING
  - COLLECTIVE-YAW COUPLING
  - AUGMENTATION REQUIREMENTS

PROJECTS PLANNED FOR FY 83-84

- AIR TO AIR SIMULATION

- FURTHER FLIGHT VERIFICATION

TASK 1 STATUS (CONT'D)

- IFR CERTIFICATION CRITERIA

ACCOMPLISHMENT

SIMULATION

- COMPLETED THREE GROUND-BASED SIMULATION EXPERIMENTS
  - STATIC STABILITY CRITERIA
  - SCAS/DISPLAY TRADE OFF
  - SINGLE vs DUAL PILOT REQUIREMENTS

FLIGHT

- IN-FLIGHT VERIFICATION WITH VARIABLE STABILITY UH-1H
  - STATIC STABILITY CRITERIA
  - SCAS/DISPLAY TRADE OFF

PROJECTS IN PROGRESS (FY 81-82)

- STATIC AND DYNAMIC STABILITY REQUIREMENTS
- EFFECTS OF INTER-AXIS COUPLING
- DECELERATED APPROACH

- IN-FLIGHT VERIFICATION USING V.S. UH-1H AND CH-47B

PROJECTS PLANNED FOR FY 83-84

- SCAS/DISPLAY FAILURE EFFECTS
- NON INSTRUMENTED TERMINAL AREAS

- FURTHER IN-FLIGHT VERIFICATION WITH V.S. UH-1H AND CH-47B
- COMPLETE DATA BASE AND DEFINE CERTIFICATION CRITERIA

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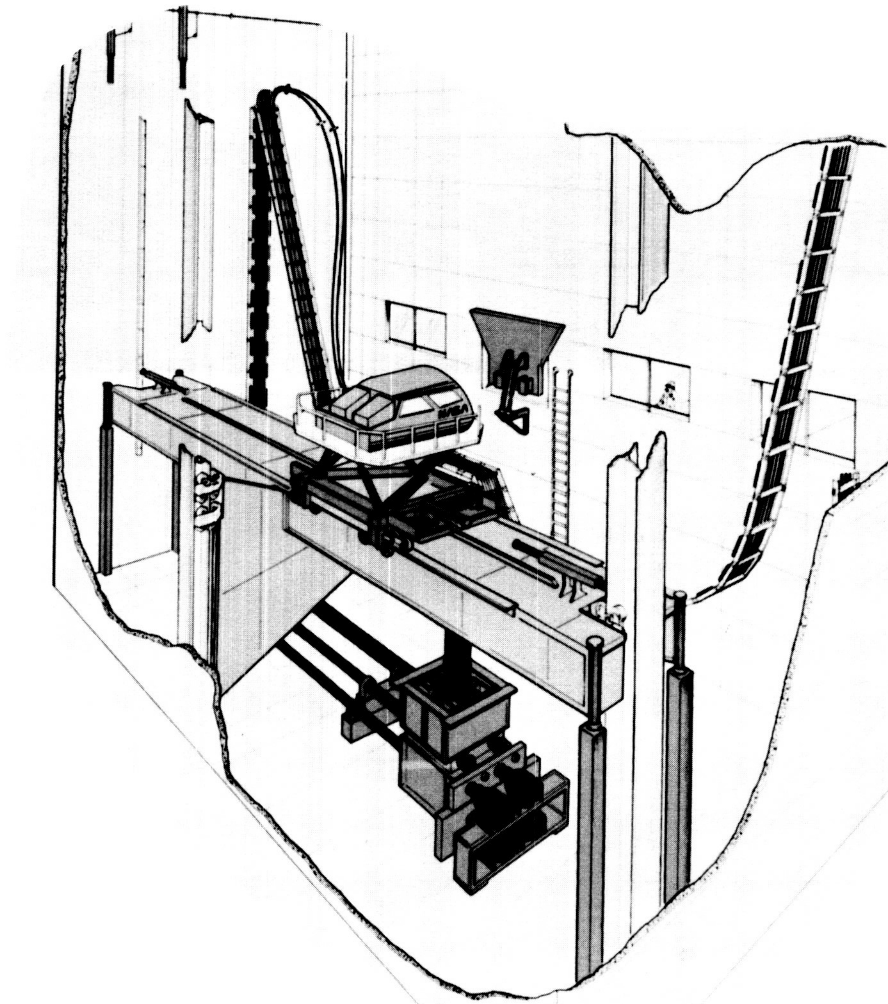
TASK 2
ADVANCED CONTROL/DISPLAY RESEARCH

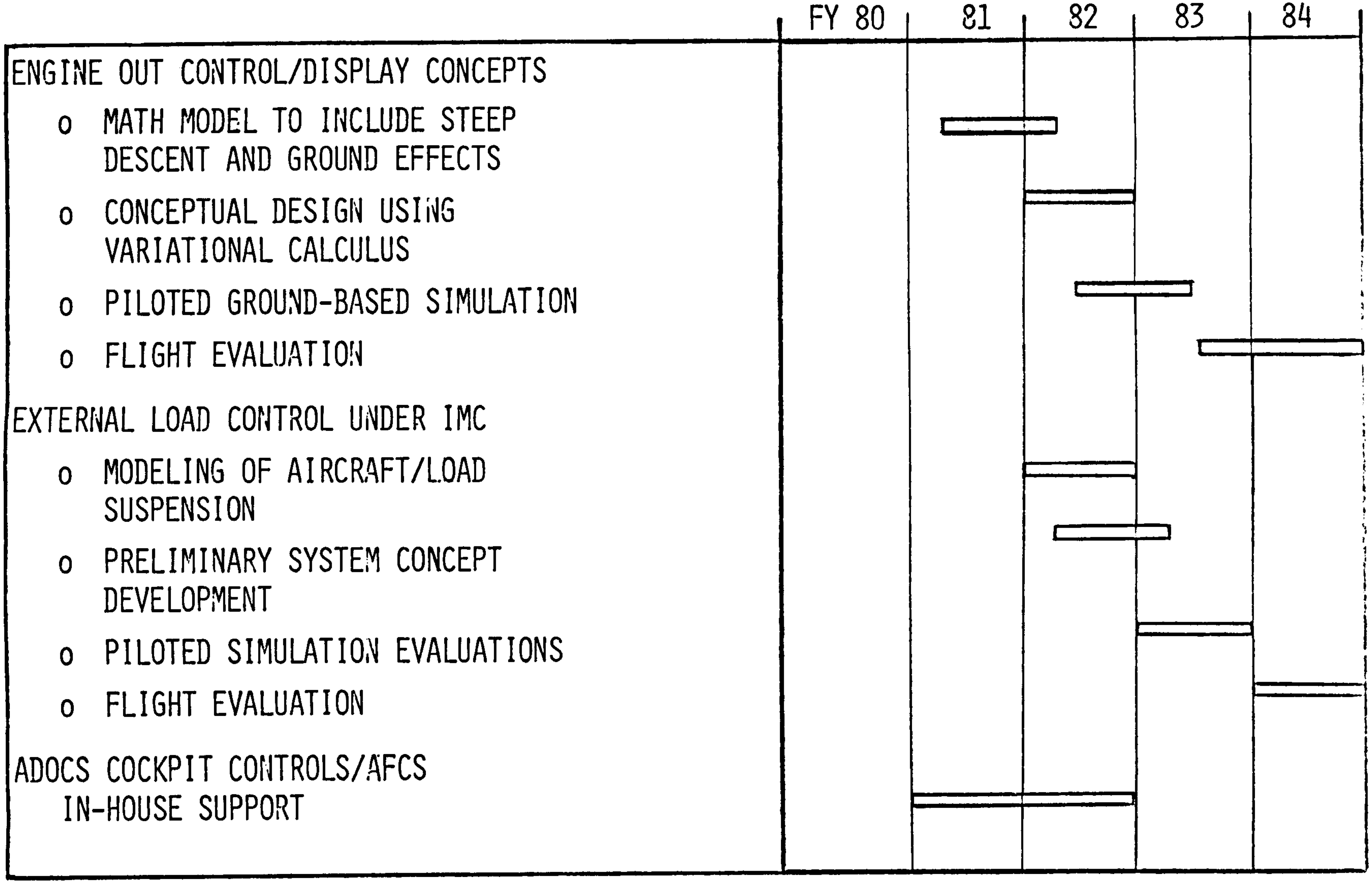
OBJECTIVES

- DEVELOP CONTROL/DISPLAY CONCEPTS FOR ENGINE OUT OPERATIONS
- DEVELOP CONTROL/DISPLAY CONCEPTS FOR EXTERNAL LOAD OPERATION UNDER IMC/VMC
- ADOCS COCKPIT CONTROLS/AFCS SUPPORT (ARMY)

APPROACH



TASK 2 STATUS



TASK 3
ANALYTICAL SUPPORT

CURRENT STATUS

PARAMETER IDENTIFICATION

- o APPLICATION AND IMPROVEMENT OF EXISTING PARAMETER IDENTIFICATION CODES
  - UH-1H
  - BO-105/BMR

SIMULATION MODEL

- o SIMPLIFIED NONLINEAR REAL-TIME MODELS
  - UH-1H (6 DOF)
  - GENERIC (10 DOF)

FUTURE PLANS (FY 81-84)

- o DEVELOPMENT OF ALTERNATIVE ID METHODS
  - INPUT DESIGN
  - NONLINEAR PARA. ID
- o APPLICATION TO UH60A, CH47B
- o INDUSTRY APPLICATIONS AND IMPROVEMENT

- o IMPROVEMENT OF GENERIC MODEL
  STEEP DESCENT
  GROUND EFFECT
- o CH47 SIMULATION MODEL
  SLUNG LOAD
- o STATE OF ART REAL-TIME BLADE ELEMENT MODEL

HELICOPTER FLIGHT CONTROL AND AVIONICS

ONGOING PROGRAMS

TASK 1: DEVELOPMENT OF TOTAL AUTOMATIC FLIGHT CONTROL SYSTEM (TAFCOS)

TASK 2: FAULT-TOLERANT IMPLEMENTATION OF TAFCOS

TASK 3: TAFCOS DESIGN FOR MULTILIFT

PROPOSED PROGRAMS

(FY 83 NEW INITIATIVES)

TASK 4: ADVANCED ACTIVE CONTROL SYSTEMS TECHNOLOGY

TASK 5: ACTIVE CONTROL APPLICATIONS

FLIGHT CONTROL AND AVIONICS

TASK 1: DEVELOPMENT OF TOTAL AUTOMATIC FLIGHT CONTROL SYSTEM (TAFCOS) FOR ROTORCRAFT

OBJECTIVE

DEVELOP METHODOLOGY FOR THE DESIGN OF HELICOPTER FLIGHT CONTROL SYSTEM TO ENHANCE MISSION PERFORMANCE BY EFFECTIVELY INTEGRATING AIRFRAME, PROPULSION, AND SUBSYSTEM CONTROL FUNCTIONS

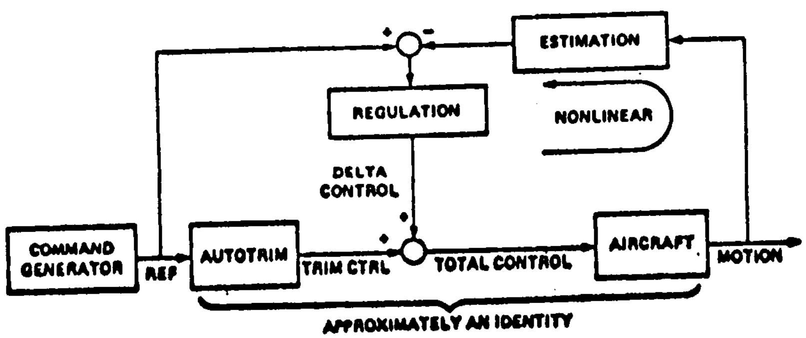
APPROACH

- o APPLICATION OF NONLINEAR SYSTEMS INVERSE THEORY
  - \- ACCELERATION COMMAND SYSTEM
- o COMPUTER CODE DEVELOPMENT, GROUND SIMULATION, AND FLIGHT EVALUATION

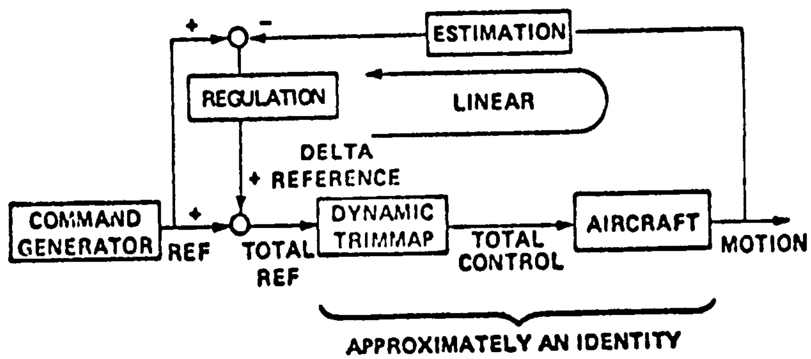
TASK 1

APPROACH (CONT'D)

CONVENTIONAL FLT CONTROL SYSTEM STRUCTURE



TAFCOS STRUCTURE



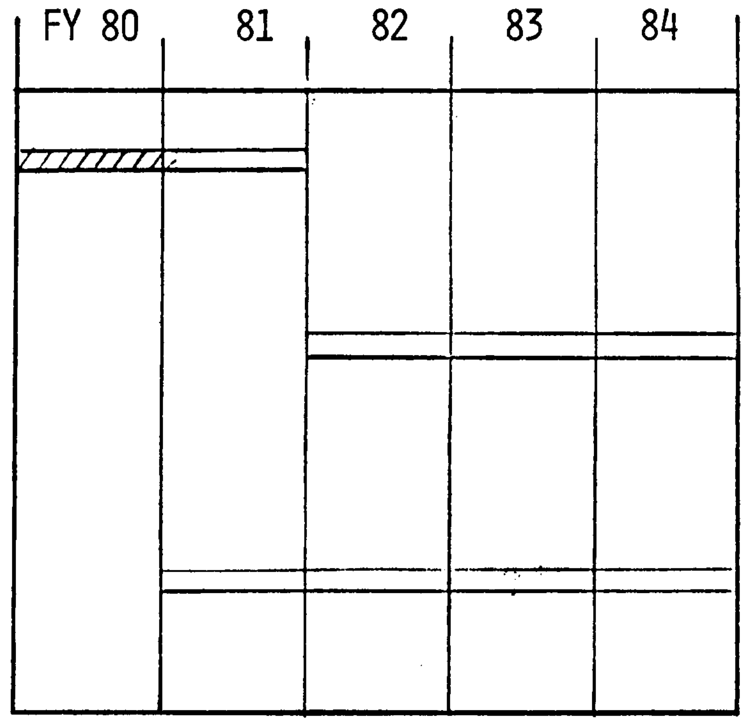
TASK 1

STATUS

FLIGHT TEST TAFCOS CONTROL CODE FOR UH-1H

TAFCOS CONTROL AND ESTIMATION CODE FOR UH-1H WITH FAULT-TOLERANCE SENSING AND COMPUTING

TILT ROTOR TAFCOS DESIGN EVALUATION AND SIMULATION



TASK 2

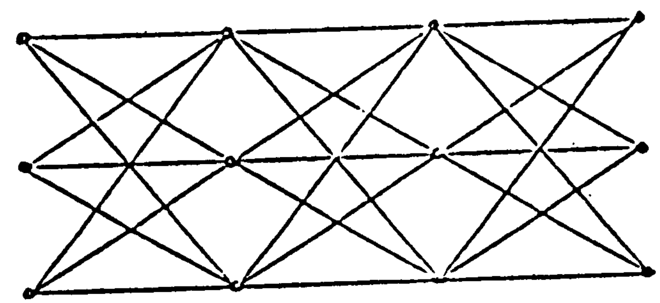
FAULT-TOLERANT IMPLEMENTATION OF TAFCOS

OBJECTIVES

DEVELOP ADVANCED CONCEPTS AND MEANS OF MECHANIZATION TO PROVIDE FAULT-TOLERANT COMPUTATION, DATA COMMUNICATION, AND ACTUATION TO IMPLEMENT THE TAFCOS.

APPROACH

- o FAULT-TOLERANT COMPUTATION
  - REDUNDANT ASYNCHRONOUS MICROPROCESSOR SYSTEM (RAMPS)

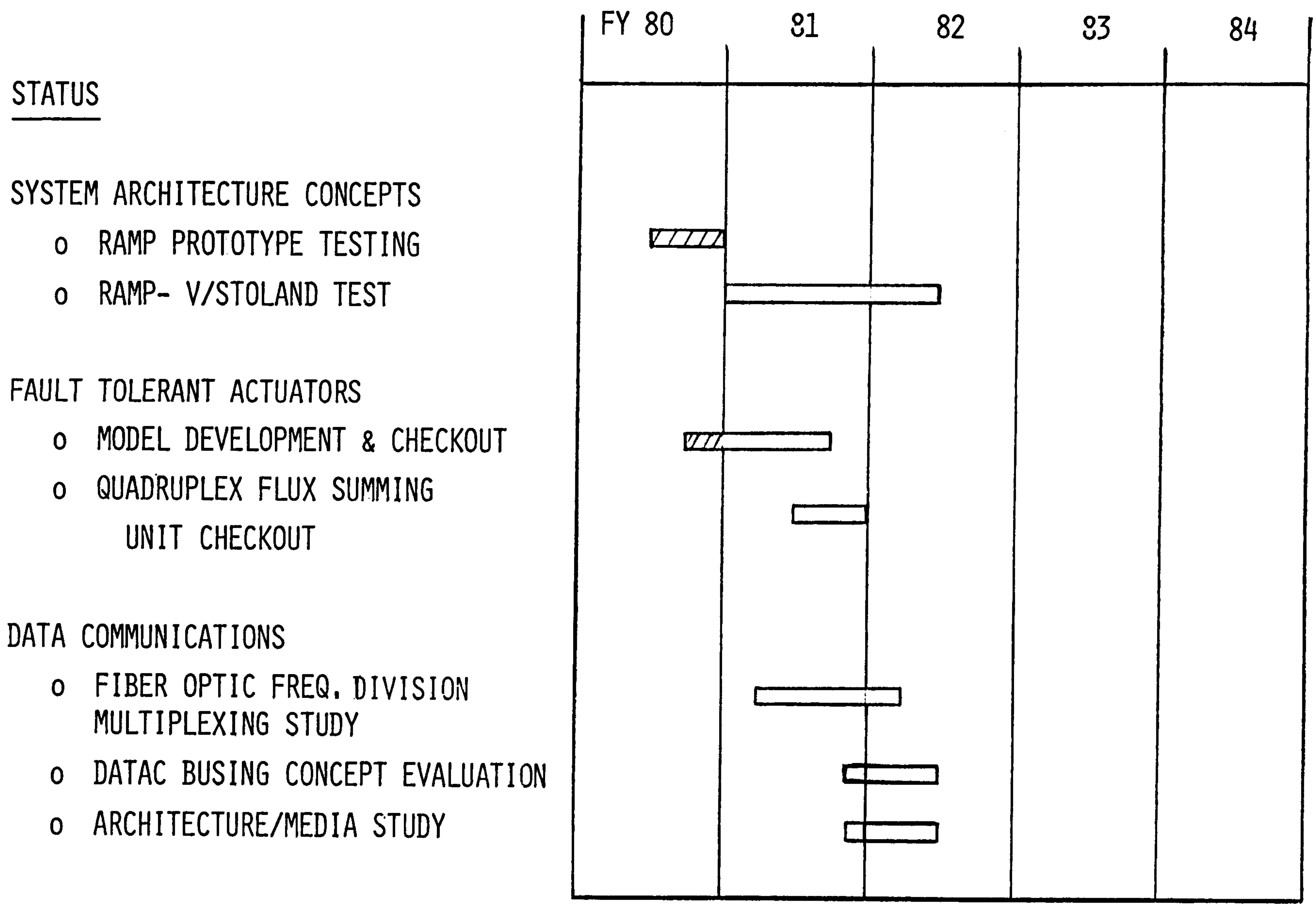


NO GLOBAL EXECUTIVE
NO CORE SOFTWARE
NO SYNCHRONIZATION

- o FAULT TOLERANT ACTUATION
  - FLUX SUMMING
- o FAULT TOLERANT DATA COMMUNICATION
  - FREQUENCY DIVISION MULTIPLEXING

TASK 2

FAULT-TOLERANT IMPLEMENTATION OF TAFCOS



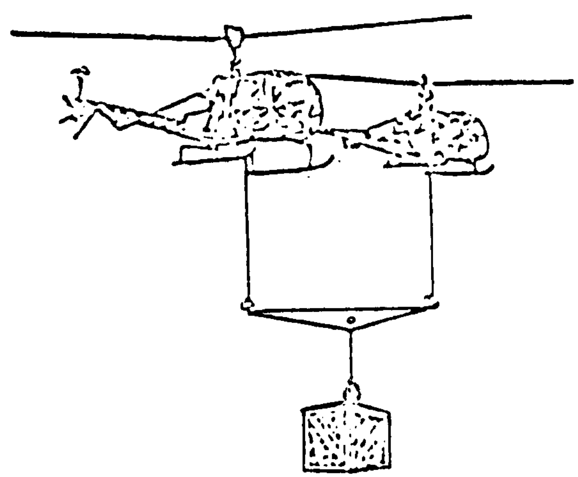
TASK 3: MULTI-LIFT

OBJECTIVE

IMPROVE OPERATIONAL CAPABILITY OF MULTI-LIFT

APPROACH

APPLICATION OF TAFCOS CONCEPTS



PHASE I LOW SPEED (LINEAR)
- REGULATION REQUIREMENTS
- SENSOR REQUIREMENTS
- COMMUNICATION REQUIREMENTS
- PILOTING REQUIREMENTS

PHASE II CRUISE (NONLINEAR)

STATUS

- o TAFCOS DESIGN ANALYSIS FOR MULTI-LIFT TO BE COMPLETED BY FY 82
- o MANNED SIMULATION EVALUATIONS IN FY 82-83

TASK 4

ADVANCED ACTIVE CONTROL SYSTEMS TECHNOLOGY

(PROPOSED NEW INITIATIVE IN FY 83)

- SYSTEMS ARCHITECTURE CONCEPTS
    - FULL AUTHORITY FBW/L
    - FAULT TOLERANT
- SUBSYSTEMS TECHNOLOGY
    - REDUNDANT DISTRIBUTED COMPUTATION NETWORK
    - REDUNDANT ACTUATORS
    - DATA COMMUNICATION
- VERIFICATION AND VALIDATION OF DIGITAL SYSTEM
- INTEGRATION OF ACTIVE CONTROL MODES
    - ACTIVE CONTROL SYSTEMS TO ENHANCE MISSION CAPABILITY (TASK 5)
- FLIGHT EVALUATION

TASK 5

ACTIVE CONTROL APPLICATIONS

(PROPOSED NEW INITIATIVE IN FY 83)

- o GUST ALLEVIATION
- o ENVELOPE LIMITING
  - TAIL ROTOR STALL PREVENTION
  - PILOTING AIDS FOR AUTOROTATION
- o ACTIVE EMPENNAGE CONTROL
- o INTEGRATED FLIGHT/PROPULSION CONTROLS

NASA ALL-WEATHER ROTORCRAFT PROGRAM

AMES RESEARCH CENTER

JOHN BULL

NASA ALL-WEATHER ROTORCRAFT PROGRAM

- o GOAL, OBJECTIVES
- o RESEARCH FACILITIES
- o PROGRAM ELEMENTS

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NASA ALL-WEATHER ROTORCRAFT PROGRAM

GOAL

- MISSION PRODUCTIVITY UNDER IMC CONDITIONS EQUIVALENT TO THAT UNDER VMC CONDITIONS

OBJECTIVE

- INCREASE ALL-WEATHER OPERATIONAL CAPABILITY
  - IMPROVED USE OF EXISTING TECHNOLOGY
  - DEVELOPMENT OF ADVANCED CONCEPTS

ALL-WEATHER ROTORCRAFT PROGRAM RESEARCH FACILITIES

RESEARCH AIRCRAFT

- SH-3G HELICOPTER AND SIMULATOR
- UH-1H HELICOPTER AND SIMULATOR
- XV-15 TILT ROTOR AND SIMULATOR

FLIGHT TEST AREAS

- CROWS LANDING NAVY AUXILIARY FIELD
- DIABLO RANGE HELIPAD
- PACIFIC COAST OFFSHORE OIL RIGS

ALL-WEATHER ROTORCRAFT PROGRAM ELEMENTS

REMOTE SITES "ON BOARD" ALL-WEATHER SYSTEMS (SH-3G)

- AIRBORNE RADAR APPROACHES
- MULTI-SPECTRAL IMAGING SYSTEMS
- NAVSTAR GPS CIVIL ROTORCRAFT APPLICATIONS

HIGH DENSITY ALL-WEATHER SYSTEMS (UH-1H)

- MICROWAVE LANDING SYSTEM PRECISION APPROACHES
- 3D/4D OPTIMAL GUIDANCE, ATC INTERFACE
- LOW COST INTEGRATED CAT III AVIONICS

ADVANCED ROTORCRAFT SYSTEMS (UH-1H, XV-15)

- NAVIGATION AND DISPLAY CONCEPTS
- AUTOLAND HELICAL APPROACHES
- SHIPBOARD NAVTOLAND SYSTEMS

AIRBORNE RADAR APPROACHES (ARA)

OBJECTIVE

- DEVELOP AIRBORNE RADAR FOR HELICOPTER IMC APPROACHES

APPROACH

- NASA/FAA FLIGHT TESTS IN GULF OF MEXICO
- CONTRACTOR HARDWARE DEVELOPMENT, UNIVERSITY GRANTS
- HELICOPTER ARA SIMULATION
- SH-3G FLIGHT TESTS

RESEARCH INVESTIGATIONS

- ARA OVERWATER RADAR TARGET AUTO TRACKER
- ARA OVERLAND RADAR PULSE PAIR DECODER
- ARA FLIGHT DIRECTOR

MULTI-SPECTRAL IMAGING SYSTEMS

OBJECTIVE

- INVESTIGATE HIGH RESOLUTION MULTI-SPECTRAL IMAGING SYSTEMS FOR HELICOPTER IMC APPROACHES

APPROACH

- UNIVERSITY GRANTS
- CONTRACTOR STUDIES AND HARDWARE DEVELOPMENT
- LAB TESTS, SH-3G FLIGHT TESTS

RESEARCH AREAS

- MM RADAR (94 GHz)
- ROTOR BLADE RADAR ANTENNA
- SIGNAL PROCESS IMAGE ENHANCEMENT

NAVSTAR GPS CIVIL HELICOPTER APPLICABILITY

OBJECTIVE

- INVESTIGATE NAVSTAR GPS APPLICATIONS FOR CIVIL HELICOPTER MISSION ENVIRONMENT

APPROACH

- Z-SET AVIONICS ON LOAN FROM AIR FORCE
- CONTRACTOR STUDIES AND MAINTENANCE SUPPORT
- LAB TESTS, SH-3G FLIGHT TESTS

RESEARCH AREAS

- LANDING APPROACH PERFORMANCE
- PILOT CONTROL INTERFACES
- ENHANCED CIVIL GPS PERFORMANCE

MICROWAVE LANDING SYSTEM (MLS) PRECISION APPROACHES

OBJECTIVE

- INVESTIGATE PRECISION APPROACH PERFORMANCE FOR VARIOUS LEVELS OF GUIDANCE, CONTROL, AND DISPLAY CONFIGURATIONS

APPROACH

- PILOTED SIMULATIONS
- UH-1H FLIGHT TESTS AT CROWS WITH BASIC NARROW TRSB MLS

RESEARCH INVESTIGATIONS

- SIMULATION INVESTIGATION OF DECELERATING APPROACHES TO HELIPAD
- JOINT NASA/FAA FLIGHT TESTS FOR TERPS CRITERIA
- JOINT NASA/FAA FLIGHT DIRECTOR FLIGHT TESTS

3D/4D OPTIMAL GUIDANCE, ADVANCED ATC CONCEPTS

OBJECTIVE

- INVESTIGATE OPTIMAL GUIDANCE AND ADVANCED ATC CONCEPTS

APPROACH

- ANALYTICAL STUDIES
- PILOTED SIMULATIONS

RESEARCH AREAS

- 3D/4D GUIDANCE CONCEPTS
- OPTIMAL GUIDANCE FOR MINIMIZING FUEL CONSUMPTION AND GROUND NOISE
- ADVANCED GUIDANCE INTERFACE WITH ATC ENVIRONMENT
- COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI)

LOW COST INTEGRATED CAT III AVIONICS

OBJECTIVE

- DEVELOP A LOW COST INTEGRATED CAT III AVIONICS SYSTEM FOR CIVIL HELICOPTER MISSIONS

APPROACH

- ADAPT TECHNOLOGY FROM THE LOW COST GENERAL AVIATION "DEMONSTRATION ADVANCED AVIONICS SYSTEM" (DAAS)
- UTILIZE ADVANCED OPERATIONAL CONCEPTS DEVELOPED IN OTHER PROGRAM ELEMENTS

RESEARCH AREAS

- RELIABILITY
- COST EFFECTIVE AVIONICS ARCHITECTURE
- INTEGRATED PILOT CONTROLS AND DISPLAYS
- AVIONICS REQUIREMENTS FOR IMPLEMENTING OPTIMAL FLIGHT MANAGEMENT AND CAT III CAPABILITY

ADVANCED NAVIGATION AND DISPLAY CONCEPTS

OBJECTIVE

- DEVELOP AND EVALUATE ADVANCED NAVIGATION AND DISPLAY CONCEPTS FOR IMC APPROACHES

APPROACH

- IN-HOUSE CONCEPT DEVELOPMENT
- ANALYTICAL STUDIES, PILOTED SIMULATIONS
- UH-1H FLIGHT TESTS

RESEARCH AREAS

- PERFORMANCE COMPARISON OF COMPLEMENTARY AND KALMAN FILTERS
- HYBRID LOW COST INERTIAL SYSTEM CONCEPTS
- TETRAD LASER GYRO PERFORMANCE
- DISPLAY DESIGN ANALYTICAL METHODOLOGY USING PILOT MODELS

AUTOLAND HELICAL APPROACHES

OBJECTIVE

- INVESTIGATE IFR HELICAL APPROACHES FOR NOISE ABATEMENT AND SEPARATION FROM FIXED WING TRAFFIC

APPROACH

- UH-1H VSTOLAND FLIGHT TESTS AT CROWS LANDING

NAVIGATION/GUIDANCE/DISPLAYS

- MLS INERTIALLY SMOOTHED
- AUTOMATIC FLIGHT CONTROL
- CRT HORIZONTAL MOVING MAP

FLIGHT PROFILE

- 1700′ RADIUS, 10° BANK AT 60 KTS
- 6° GLIDESLOPE
- HELIPAD IN OR OUT OF HELIX

NAVTOLAND SHIPBOARD AUTOLAND

OBJECTIVE

- DEVELOP AND EVALUATE AN INTEGRATED FLIGHT CONTROL AND DISPLAY SYSTEM FOR VTOL/HELICOPTER SHIPBOARD AUTOLAND

PROGRAM DEVELOPMENT RESPONSIBILITIES

- PLANNING (NAVAL AIR SYSTEMS COMMAND, WASHINGTON)
- SHIPBOARD AVIONICS (NAVAL OCEAN SYSTEMS COMMAND, SAN DIEGO)
- SHIPBOARD VISUAL AIDS (NAVAL AIR ENGINEERING CENTER, LAKEHURST)
- AIRBORNE AVIONICS (NAVAL AIR DEVELOPMENT CENTER, JOHNSVILLE)
- SIMULATION SUPPORT (NASA-AMES, MOFFETT FIELD)
- FLIGHT TESTS (NAVAL AIR TEST CENTER, PATUXENT RIVER)

NASA SIMULATIONS

- HARRIER AND LIFT FAN VTOL ON FSAA, VMS
- SH-2F HELICOPTER ON VMS
- SEA STATE 5: (12 FT WAVES, 25 KT WINDS)

RADAR TARGET AUTO TRACKER

OBJECTIVE

- PROVIDE AUTOMATIC TARGET TRACKING CAPABILITY OVERWATER WITH COMMERCIAL WEATHER/MAPPING RADAR

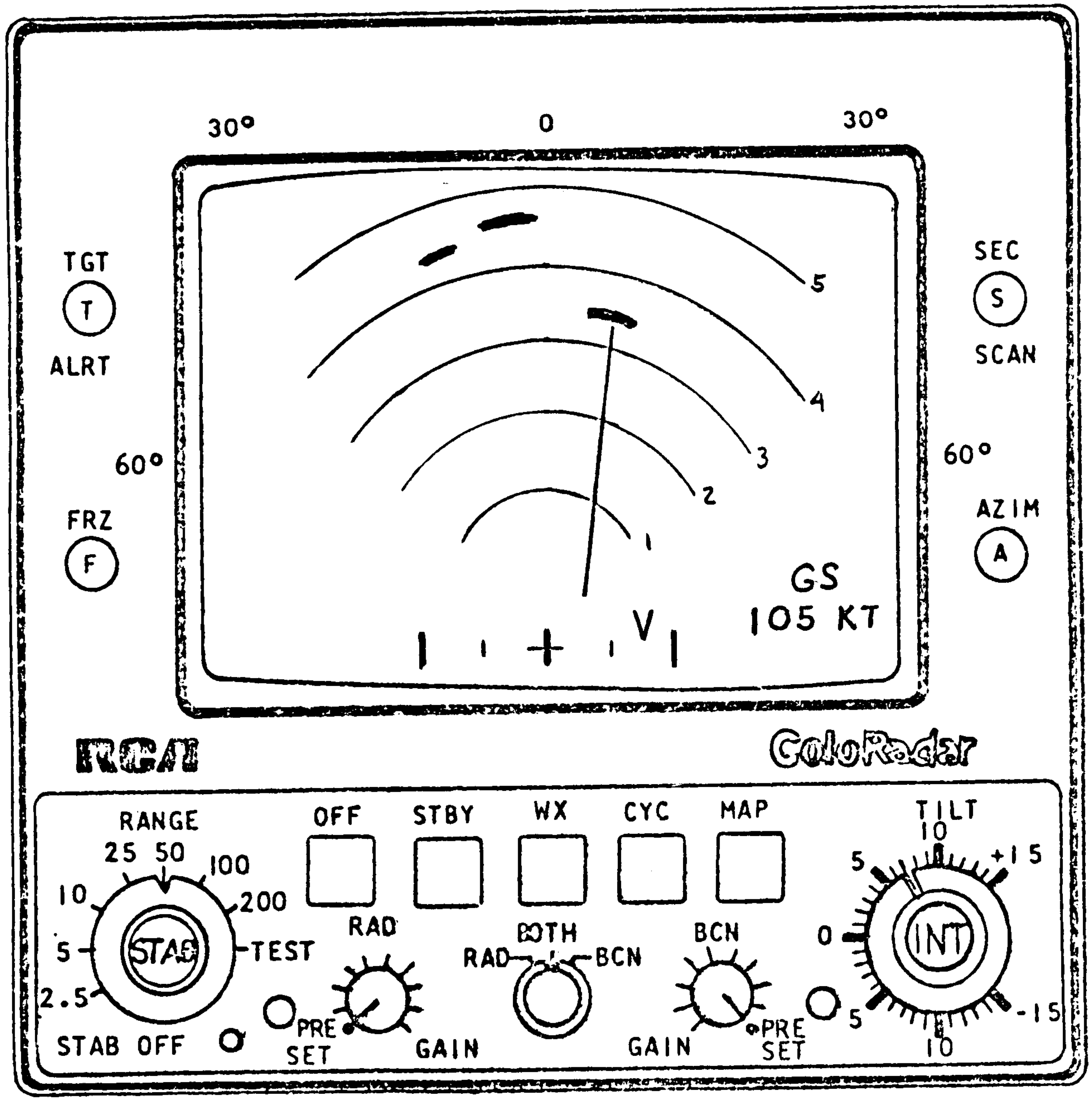
BENEFITS

- AUTOMATIC TARGET TRACKING
- AUTOMATIC GAIN AND TILT CONTROL
- GROUND TRACK COURSE DEVIATION INDICATION
- REDUCED PILOT WORKLOAD AND LOWER WEATHER MINIMUMS

METHOD

- HARDWARE DEVELOPMENT UNDER CONTRACT
- SH-3G FLIGHT TESTS OVER PACIFIC

RADAR TARGET AUTO TRACKER



RADAR PULSE PAIR DECORDER

OBJECTIVE

- PROVIDE AUTOMATIC DETECTION OF RADAR REFLECTORS IN HIGH CLUTTER ENVIRONMENT

BENEFIT

- OVERLAND RADAR APPROACHES POSSIBLE USING ONLY PASSIVE REFLECTORS

METHOD

- EXPERIMENTAL HARDWARE DEVELOPMENT IN COOPERATIVE AGREEMENT WITH UNIVERSITY OF NEVADA
- MOBILE VAN GROUND TESTS
- LEAR JET, SH-3G FLIGHT TESTS

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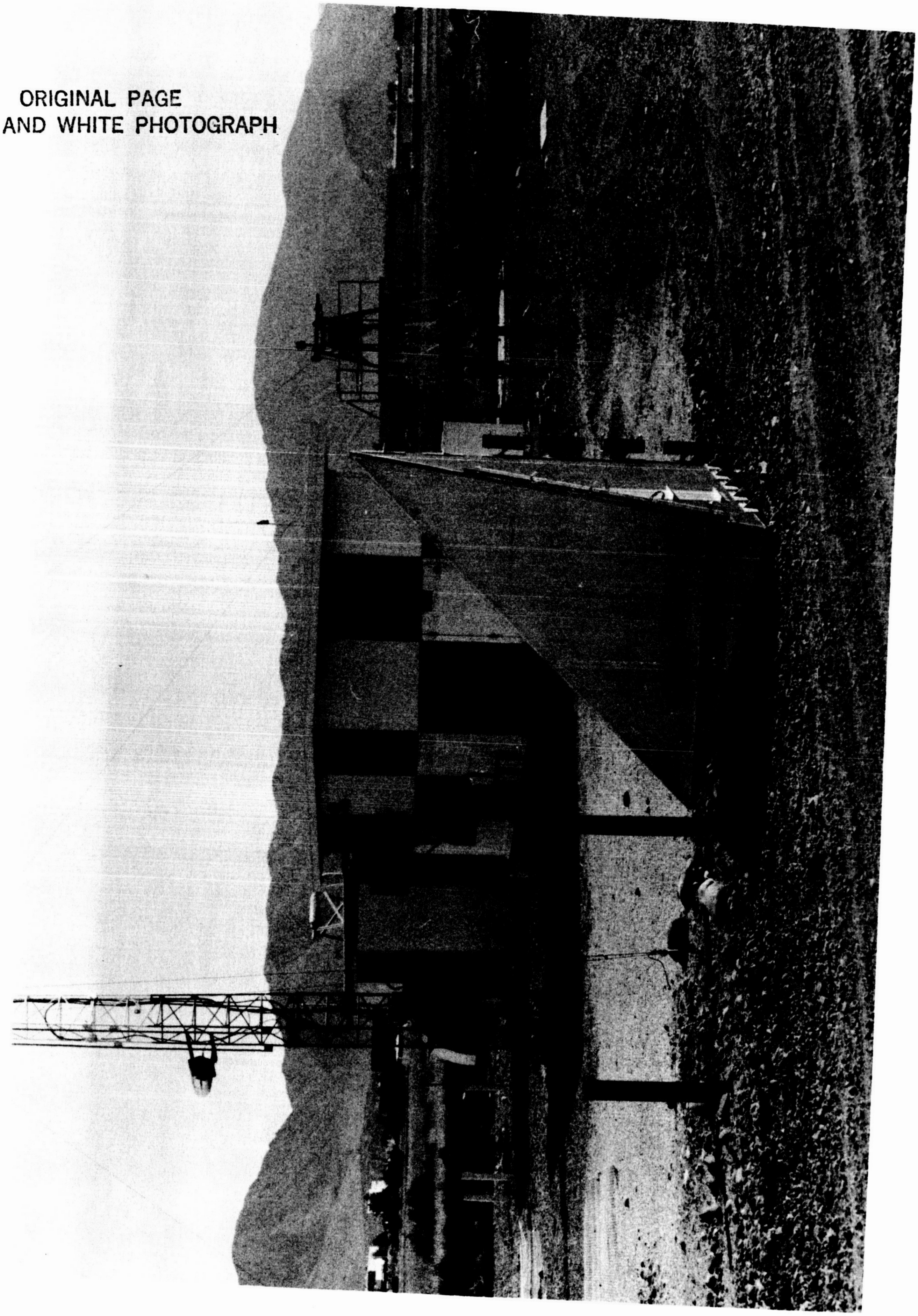

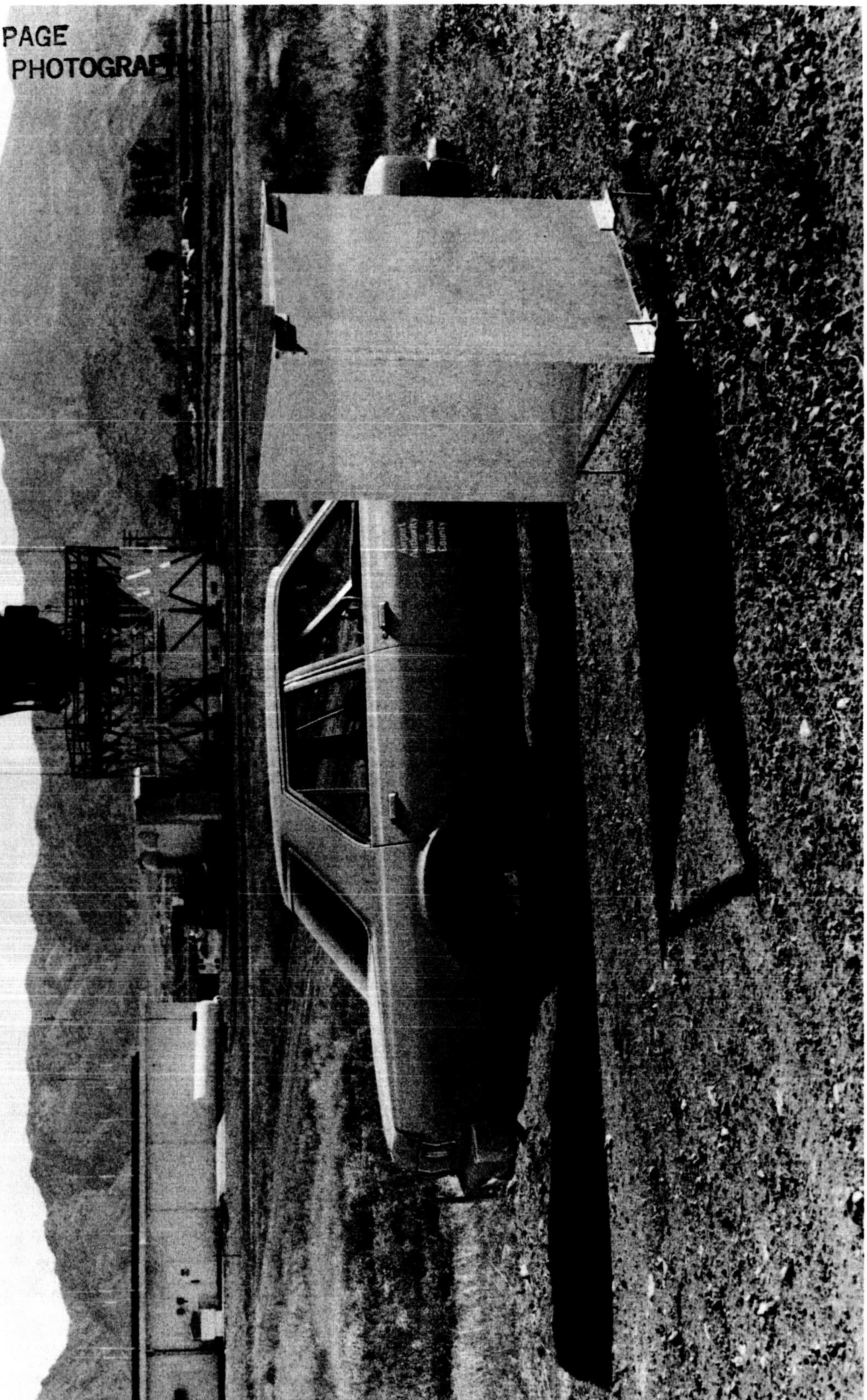

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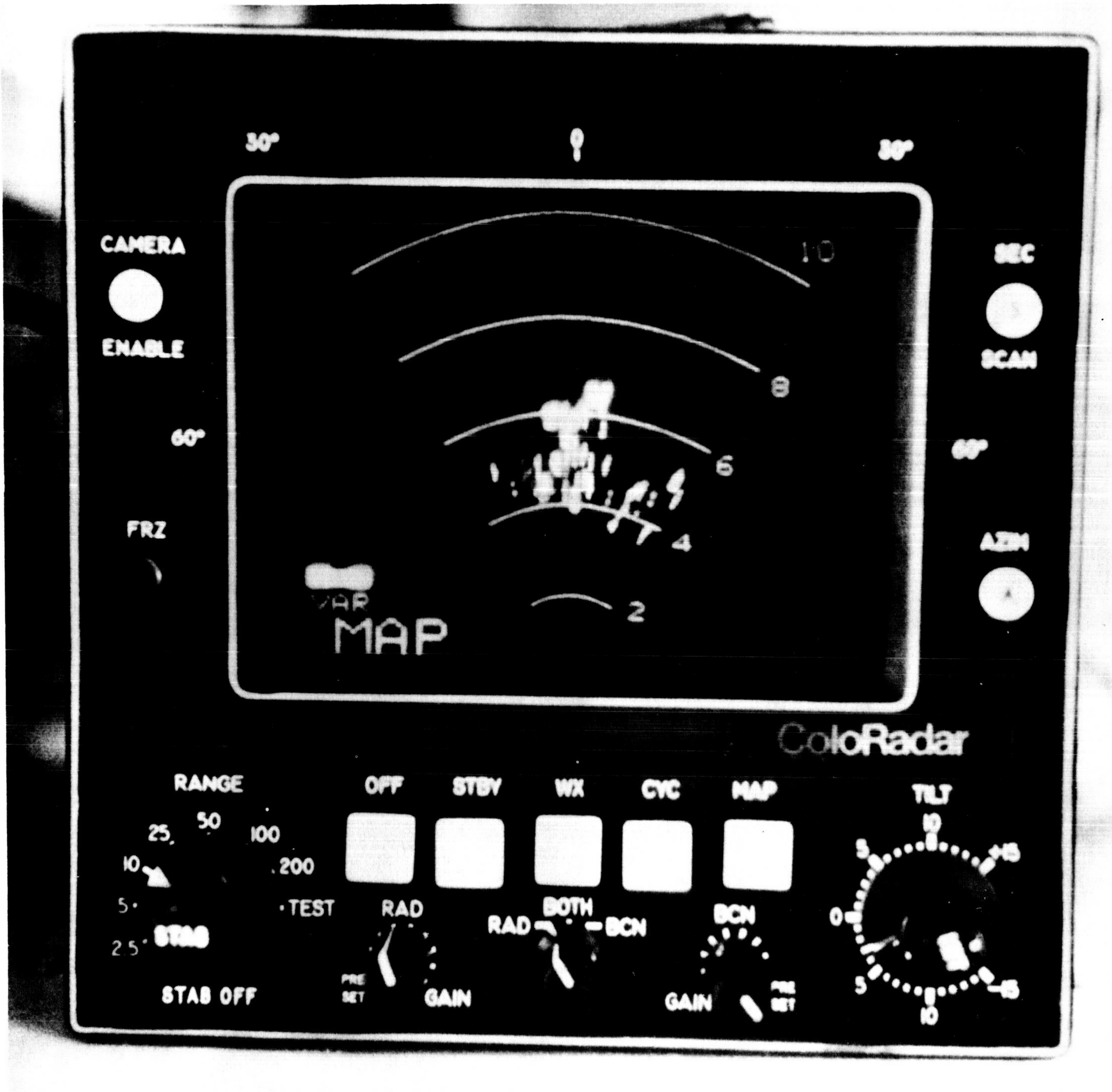
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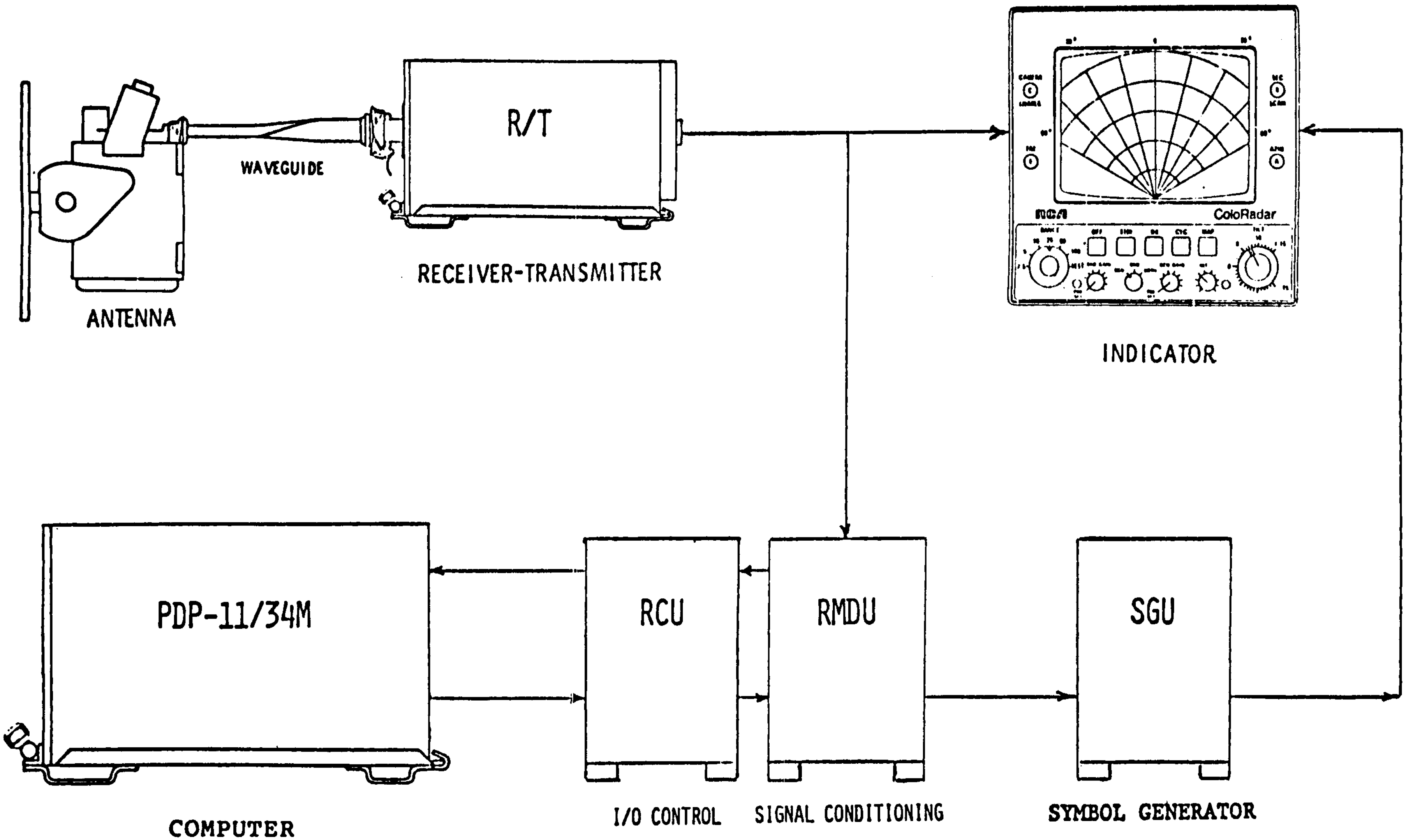
SH-3G RADAR RESEARCH AVIONICS SYSTEM

- PROCESS RAW RADAR SIGNALS
- GENERATE ARBITRARY DISPLAYS



SH-3G AIRBORNE RADAR OPERATING EXPERIMENTS

FLIGHT DIRECTOR (SUPERIMPOSED ON RADAR CRT)

- COURSE DEVIATION INDICATOR
- HEADING AND ALTITUDE COMMANDS
- ATTITUDE AND COLLECTIVE COMMANDS
- INTEGRATED DISPLAY

IMPROVED TRACKING

IMAGE ENHANCEMENT

- COLOR
- COMPUTED CENTER OF MASS
- INCREASED SHADING

TARGET IDENTIFICATION

- STORED TARGETS
- AREA MATCHING
- SIGNAL PATTERN RECOGNITION

AUTOMATED OPERATION

- GAIN
- TILT
- TARGET LOCK ON

REDUCED WORKLOAD

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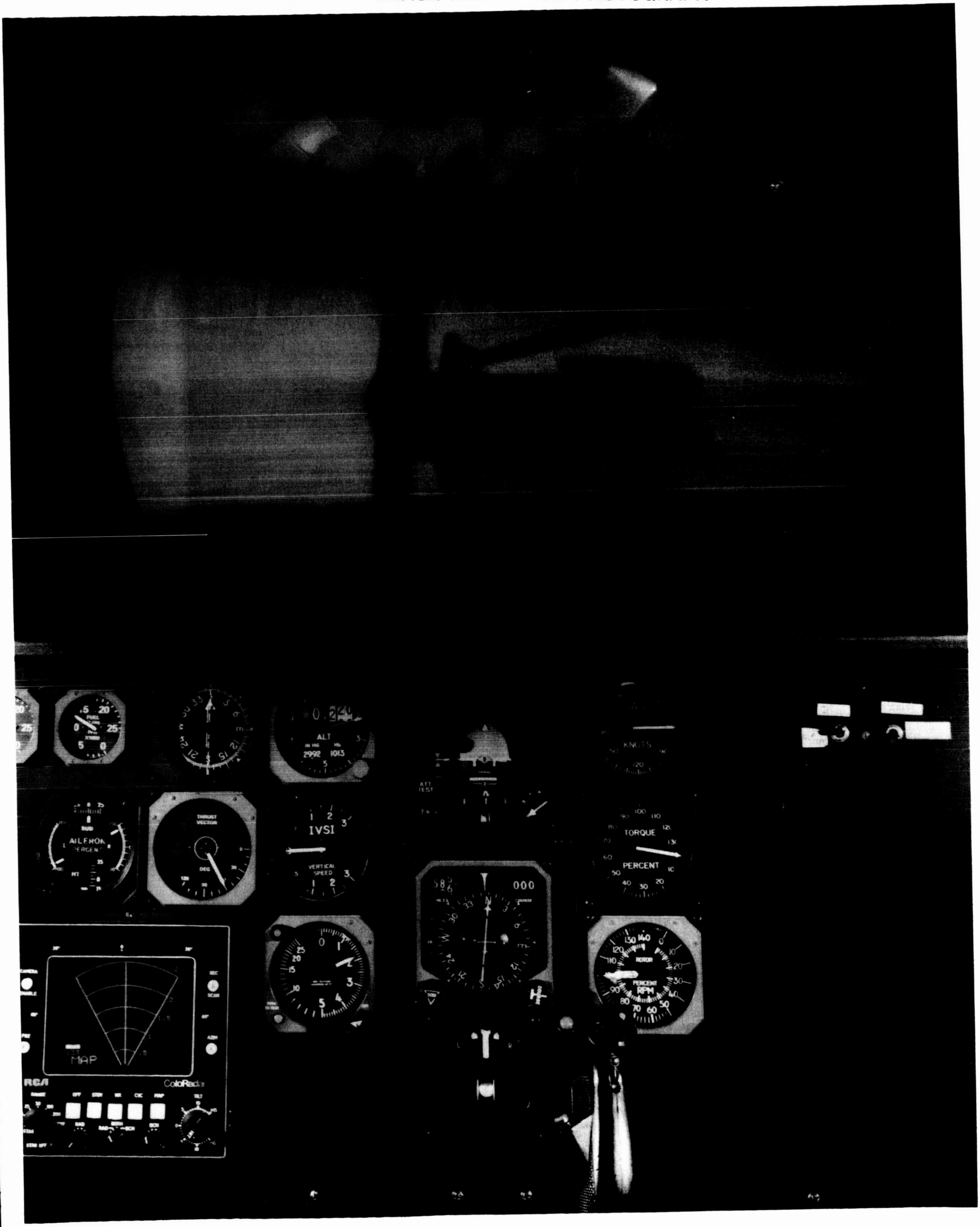

NASA HELICOPTER MAN-SYSTEM INTEGRATION

(HUMAN FACTORS)

AMES RESEARCH CENTER

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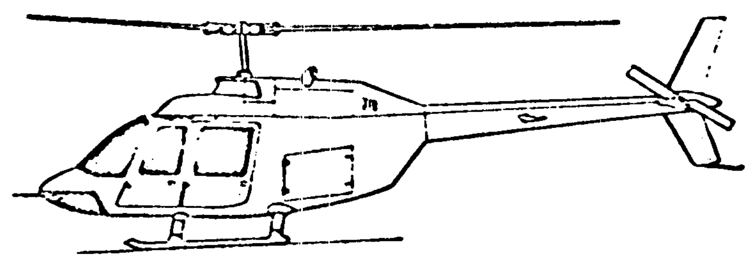
HELICOPTER MAN-SYSTEM INTEGRATION



NASA-AMES HFE OVERVIEW

o AVIATION SAFETY REPORTING SYSTEM	COMPUTERIZED DATA BASE INCIDENT STUDIES ALERT BULLETINS
o FLIGHT MANAGEMENT SYSTEMS	HEAD-UP DISPLAY CAUTION AND WARNING SYSTEM COCKPIT DISPLAY OF TRAFFIC INFORMATION EFFECTS OF AUTOMATION RESOURCE MANAGEMENT TRAINING
o SIMULATION TECHNOLOGY	LOW VISIBILITY SCENE DEVELOPMENT LOW VISIBILITY SCENE EVALUATION TRANSITION/UPGRADE TRAINING
o HELICOPTER/VTOL HFE	INTERFACE TECHNOLOGY WORKLOAD/PERFORMANCE MEASUREMENT INTEGRATION INTO ATC

HELICOPTER MAN-SYSTEM INTEGRATION

HELICOPTER SYSTEM CHARACTERISTICS

- HELICOPTERS DIFFER FROM FIXED-WING AIRCRAFT IN THAT:
  - MISSIONS ARE DIFFERENT
    - GROUND RELATED TASKS, I.E., LIFTING, SEARCHING, SPRAYING
    - NAVIGATION TO REMOTE AREAS, CITY-CENTERS, OFF-SHORE
  - FLIGHT PROFILES ARE DIFFERENT
    - LOWER AND SLOWER
    - HOVERING AND VERTICAL FLIGHT
  - FLIGHT CONFIGURATIONS ARE DIFFERENT
    - AIRWAYS FLYING
    - TRANSITION AND HOVER
  - CONTROLS ARE DIFFERENT
    - COLLECTIVE AND CYCLIC
    - TAIL ROTOR

HELICOPTER MAN-SYSTEM INTEGRATION

DISTINGUISHING HUMAN FACTORS PROBLEMS

- GREATER MANUAL CONTROL ACTIVITY
- GREATER VEHICLE INSTABILITY TO CONTROL
- GREATER TIME CRITICALITY FOR DECISION AND REACTION
- MORE CONTACT VISUAL DEMAND/ LESS SYSTEM MONITORING TIME
- MORE AVIONICS AND DISPLAY CONFIGURATIONS
- MORE NATURAL OR MAN-MADE HAZARDS TO AVOID
- GREATER VIBRATION AND NOISE STRESS
- MORE PHYSICALLY DEMANDING SCHEDULES
- GREATER VARIETY OF OPERATIONAL SKILLS FOR TRAINING

HELICOPTER HUMAN FACTORS

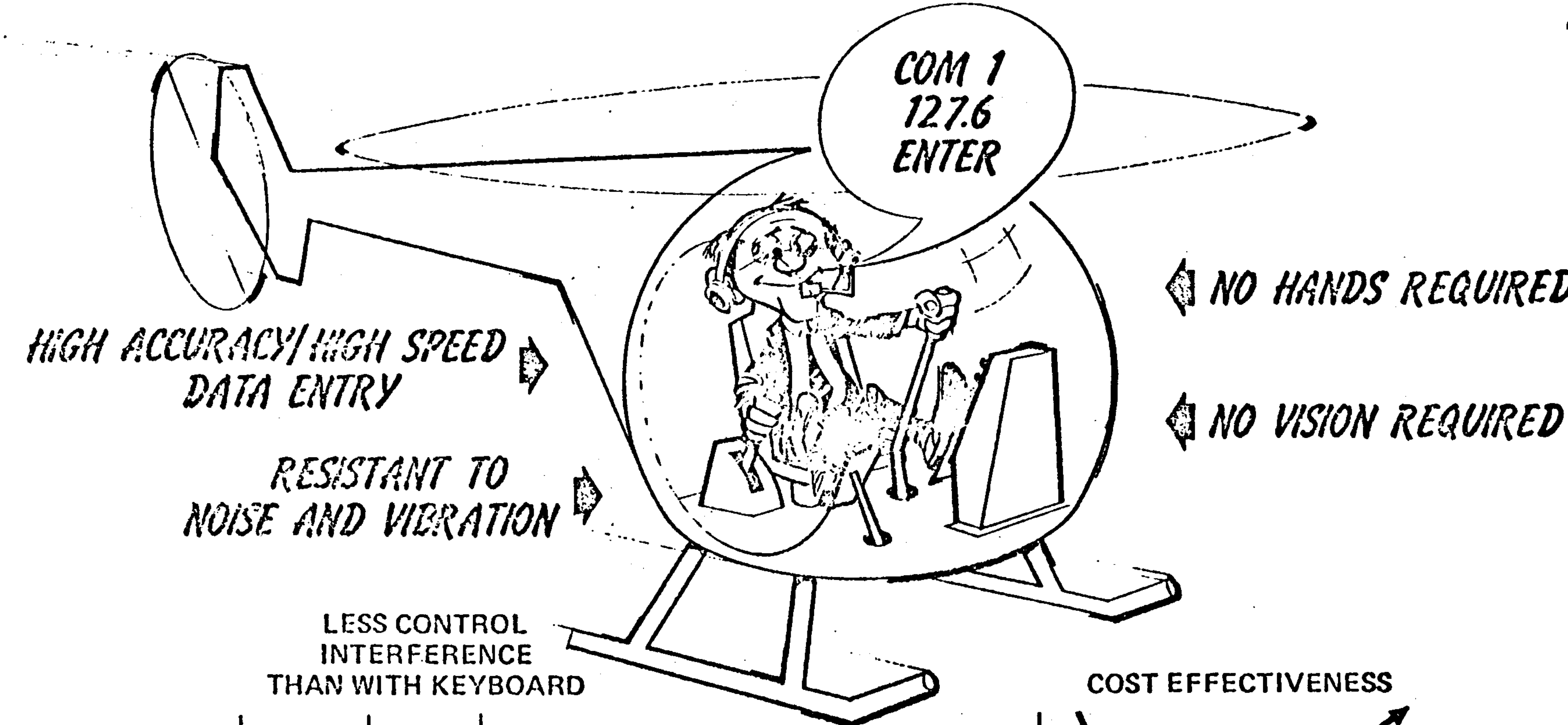
RTOP 505-42-41

o DISPLAYS AND CONTROLS FOR HELICOPTER MISSION APPLICATIONS	o VISUAL DISPLAYS FOR HOVER AND NOE o SYNTHETIC SPEECH FOR CRITICAL INFO. o AUDITORY DISPLAYS FOR OBSTACLE AVOIDANCE o AUTOMATIC SPEECH RECOGNITION o INTEGRATED CONTROLLERS
o HELICOPTER PILOT WORKLOAD AND PERFORMANCE ASSESSMENT	o FLIGHT SCENARIO IDENTIFICATION o PILOT MODEL AND PARAMETER IDENTIFICATION o MEASUREMENT SET OF SUBJECTIVE RATINGS, SECONDARY TASKS AND PHYSIOLOGICAL INDICES
o ADVANCED HELICOPTER CREW STATION DESIGN	o SYNTHESIS OF INTERFACE TECHNOLOGY o ESTABLISHMENT OF DESIGN CRITERIA o EVALUATION OF CREW STATION CONCEPTS

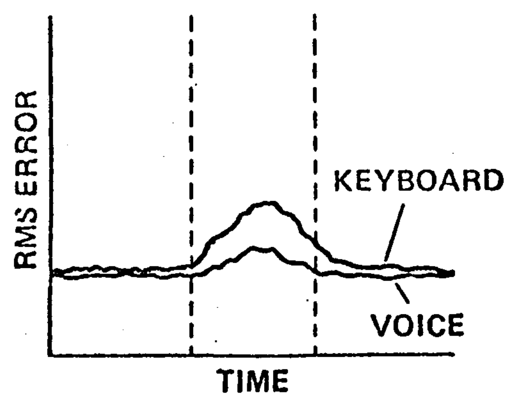
SPEECH RECOGNITION TECHNOLOGY

USE OF NATURAL LANGUAGE FOR:

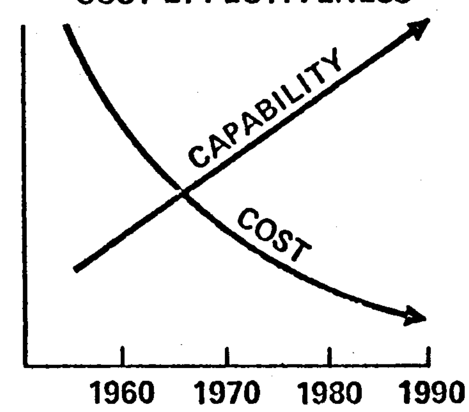
- NAVIGATION DATA ENTRY
- AVIONICS CONFIGURATION CONTROL
- DISPLAY OPTION SELECTION



LESS CONTROL INTERFERENCE THAN WITH KEYBOARD



COST EFFECTIVENESS



Preliminary Flight Test Data for VRM -- Cessna 402B

Training	In-Flight Noise (dBA)	Recognition Accuracy (%)	Rejection (%)	Vocabulary Size
One Practiced Speaker -- no noise cancelling augmentation				
Ground, 65dBA	92	98	0	10
Flight, 92	92	98	2	10
Ground, 65	92	100	25	18
Flight, 90	90	99	2	18
Ground, 90	90	90	7	36
One Practiced Speaker -- with noise cancelling augmentation				
Ground, 75	91	98	15	10
Flight, 91	91	98	3	10
Flight, 91	92	96	3	18
Ground, 76	92	89	18	36

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VOLUME IV

APPENDIX B

FLIGHT CONTROL TECHNOLOGY SUBSESSION

MANUFACTURERS PRESENTATIONS

* Bruce Blake - Boeing Vertol
* Rod Iverson - Sperry Flight Systems
* Dora Strother - Bell Helicopter-Textron
* David Key - U. S. Army Aeromechanic Laboratory
* Ted Carter - Sikorsky Aircraft

POINTS* MADE BY IVERSON

ROD IVERSON

HELICOPTER SYSTEM MARKETING REPRESENTATIVE
SPERRY FLIGHT SYSTEMS, AVIONICS DIVISION

1. Single pilot IFR system:
   - (a) Redundant system capability
   - (b) Reduce pilot workload
2. Helicopter instrumentation reaching limits of reason.

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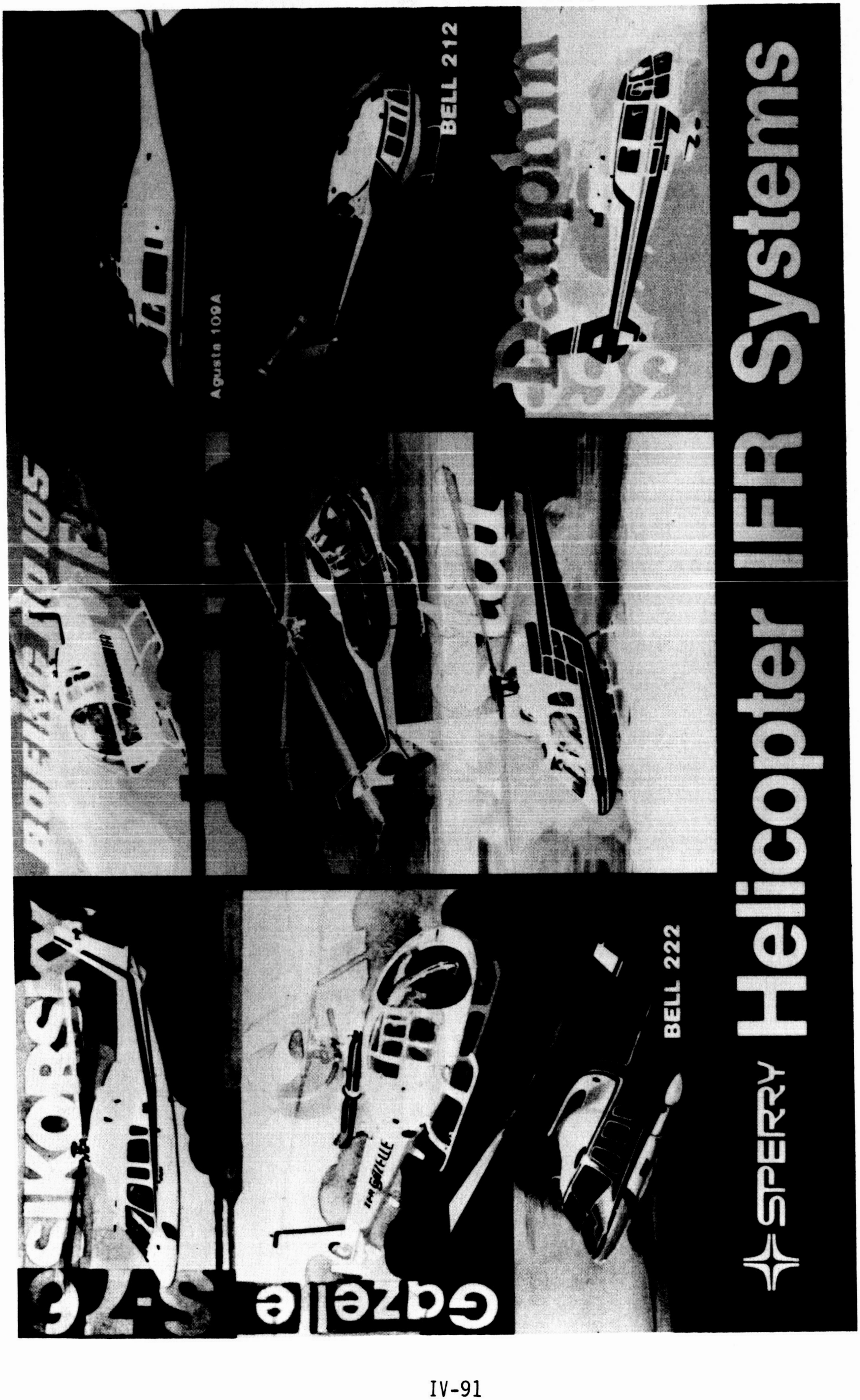

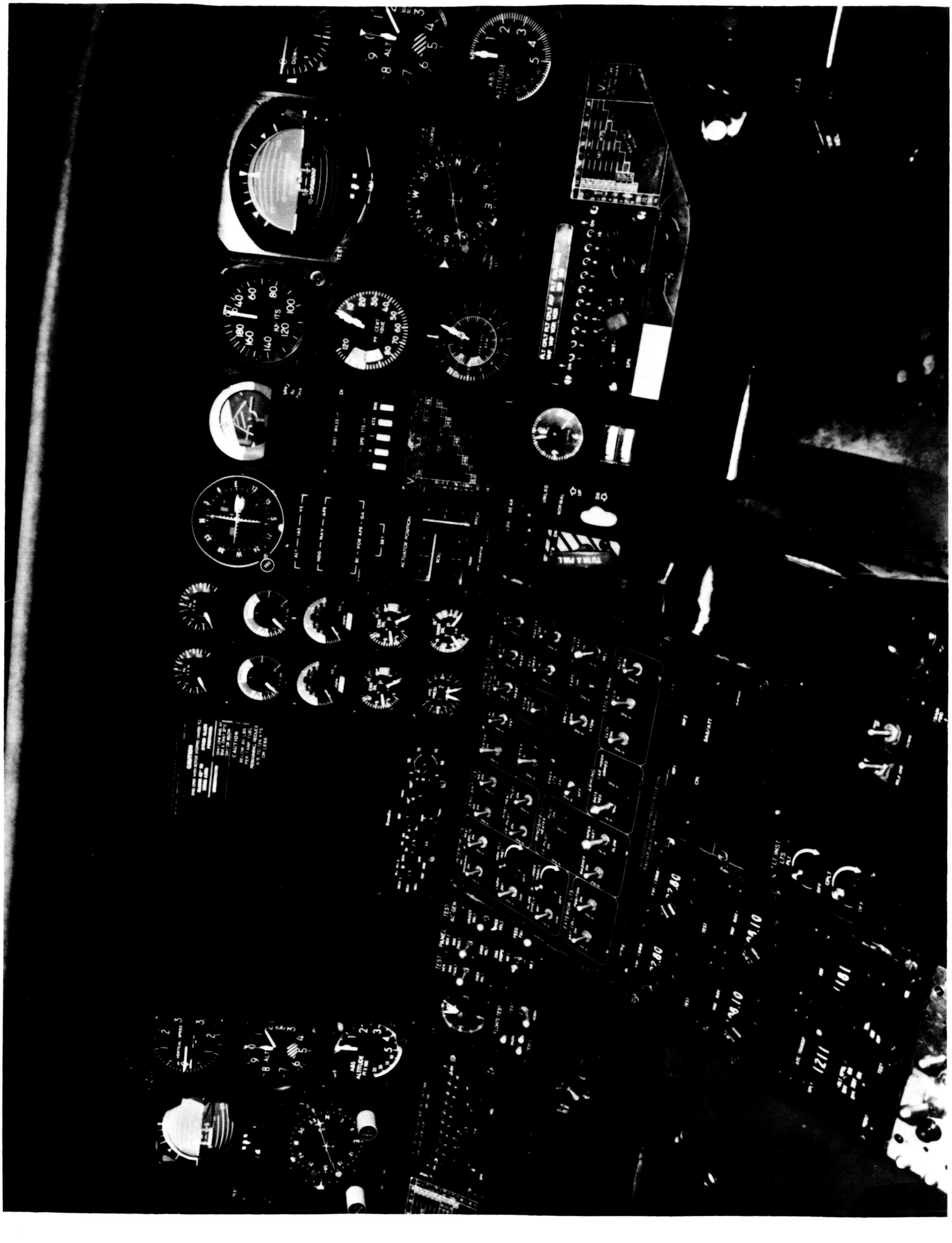

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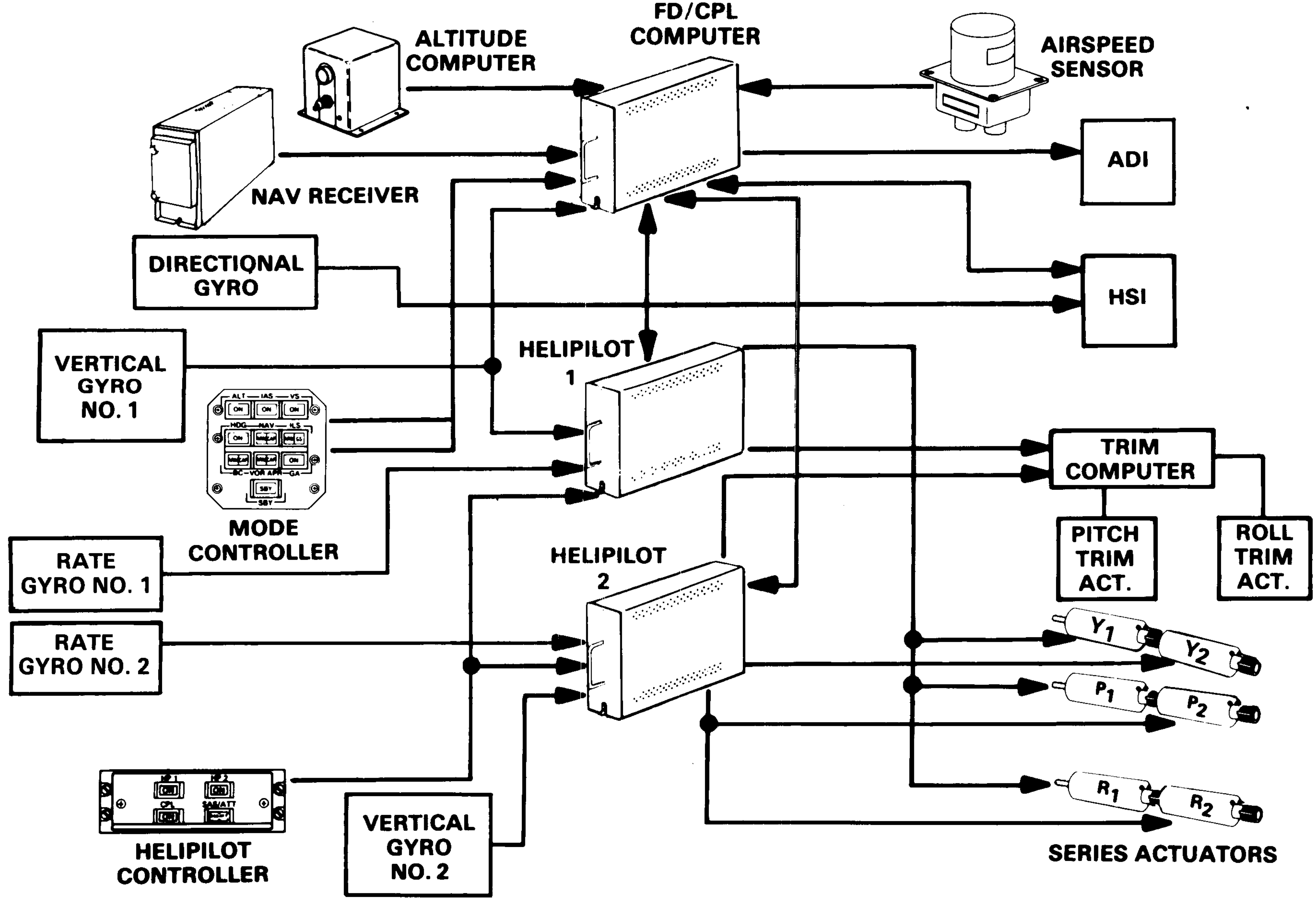
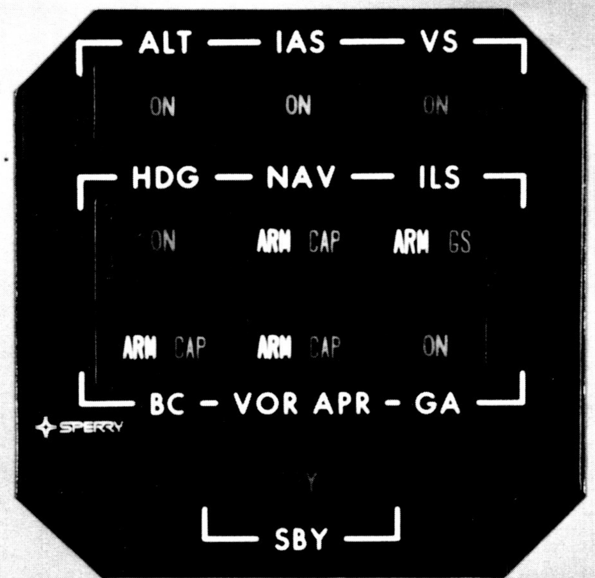
S-76
FULLY COUPLED AUTOMATIC FLIGHT





MODE SELECTOR

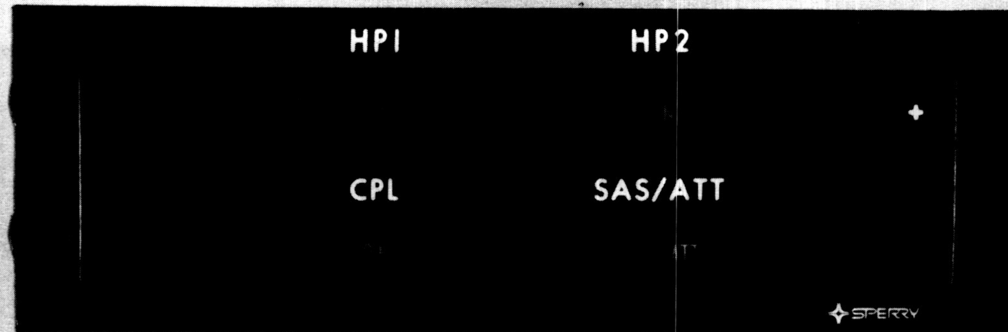
FLIGHT DIRECTOR OPERATING MODES

On-Board Sensor Coupling

- Heading Select
- Vertical Speed Select
- Barometric Altimeter Hold
- Go-Around
- Airspeed Hold

Outside Reference Coupling

- VOR
  - Enroute
  - Approach
- Localizer
- Glide Slope
- MLS (LOC/GS)
- VLF (OMEGA)
- R/NAV
- LORAN, TACAN



HELIPILOT CONTROLLER

HELIPILOT OPERATING MODES

SAS — Stability Augmentation System
- Transient Motion Rate Damping
- Pilot Cyclic Input Determines Aircraft Attitude "Rate" Response

ATT — Attitude Hold
- Transient Motion Rate Damping Plus Gyro Stabilization at Any Preselected Ship Attitude
- Pilot Cyclic Input Causes Aircraft Attitude Response

CPL — Flight Director Coupling to Ship Actuators
- ATT Plus Pilot or NAV Inputs to Avionics System (Hands-Off Flying)
- Flight Director Data Displayed on ADI

POINTS* MADE BY STROTHERS

DR. DORA STROTHERS

CHIEF OF THE HUMAN FACTORS ENGINEERING GROUP
BELL HELICOPTER - TEXTRON

1. Two-thirds of all accidents are pilot induced.
2. Areas for reducing pilot error include:
    - (a) Improved design
    - (b) Improve air traffic control and pilot interface.
    - (c) Improve flight deck instrumentation lay-out.
    - (d) Reduce fatigue and pilot workload.
3. Pilot stress relating to original learning experiences.
4. Pilot serving in flight manager role through:
    - (a) Standard control design.
    - (b) Side arm and fingertip controls.
    - (c) Force vs. rate vs. displacement.
    - (d) Control feel.
    - (e) Field of view -- how much is required and/or transparent structural materials.
    - (f) Control movement.

PRESENTATION BY

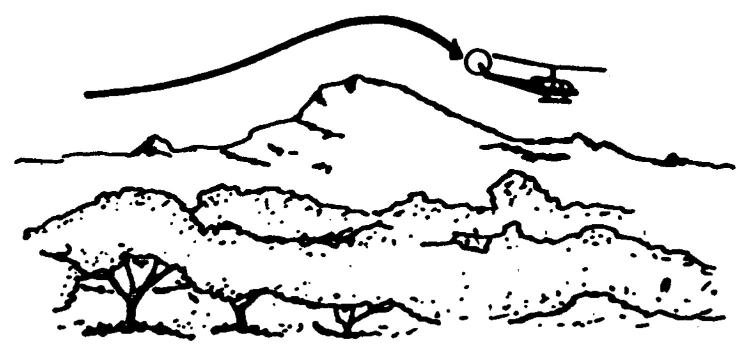
DAVID KEY

U. S. ARMY AEROMECHANICS LABORATORY

FLIGHT PHASES OF PARTICULAR CONCERN
TERRAIN FLIGHT

NOE

DAYTIME – GOOD VISIBILITY



AGILITY AND MANEUVERABILITY

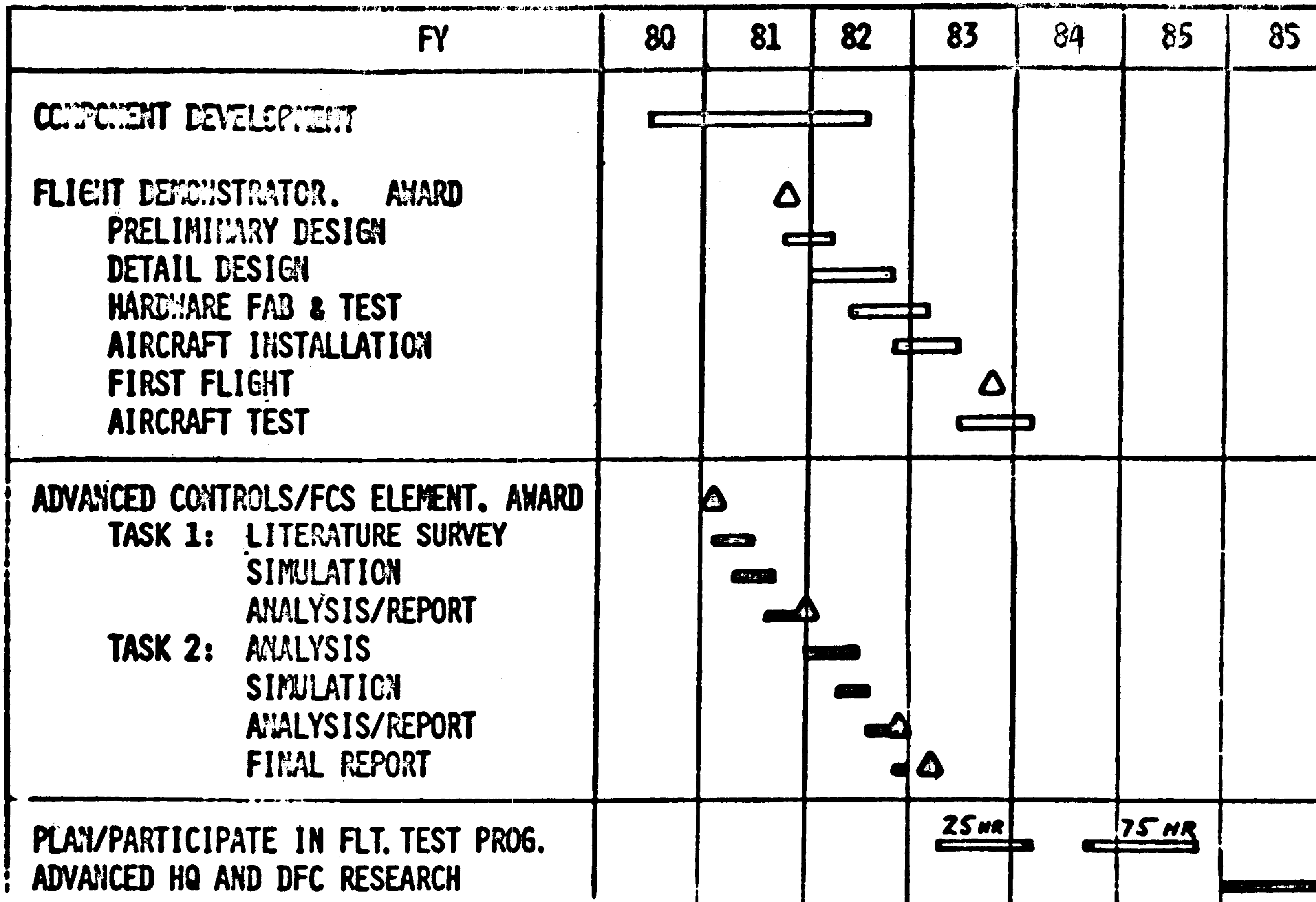
NOE

NIGHT OR POOR VISIBILITY

CONTROL, GUIDANCE

PRECISION OF CONTROL
TARGET ACQUISITION

C-2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85
COMPONENT DEVELOPMENT
FLIGHT DEMONSTRATOR. AWARD
PRELIMINARY DESIGN
DETAIL DESIGN
HARDWARE FAB & TEST
AIRCRAFT INSTALLATION
FIRST FLIGHT
AIRCRAFT TEST
ADVANCED CONTROLS/FCS ELEMENT. AWARD
TASK 1: LITERATURE SURVEY
SIMULATION
ANALYSIS/REPORT
TASK 2: ANALYSIS
SIMULATION
ANALYSIS/REPORT
FINAL REPORT
PLAN/PARTICIPATE IN FLT. TEST PROG.
ADVANCED HQ AND DFC RESEARCH
25 HR
75 HR

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APPENDIX II

COMPONENT DEVELOPMENT/CONCEPTUAL DESIGNS CONTRACTS

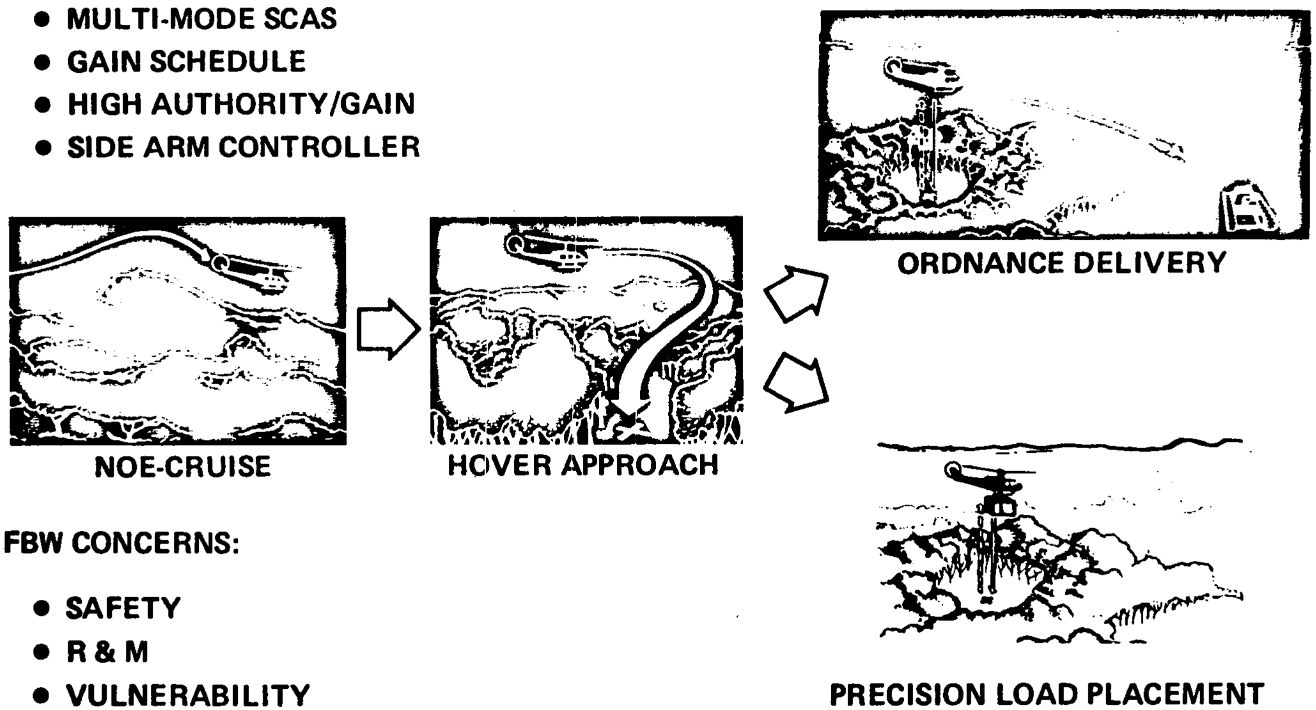
TECHNOLOGY	CONTRACTOR	POC	CONTRACT NUMBER DAAK51-	AWARD DATE / COMPLETION DAT
1 Control Media Mechanization Study	Boeing Aerospace Kent, Washington	William C. Bowman 206-251-4683	80-C-0019	30 Apr 80 / 30 Apr 81
	Harris Govt Information Systems Melbourne, Florida	Bill Matheson 305-727-5094	80-C-0018	5 May 80 / 5 May 81
2 Rotary Transducer	Hamilton-Standard Windsor Locks, Connecticut	Ed Fox 203-678-9618	80-C-0033	7 Aug 80 / 7 Feb 82
	TRW Elec Group Phila. Laboratory Phila, Pennsylvania	Malcolm Hodge 215-922-8900	80-C-0032	31 Jul 80 / 31 Jan 82
3 Linear Transducer	Boeing Aerospace Kent, Washington	Art VanAusdal 206-773-1375	80-C-0028	6 Aug 80 / 6 Feb 82
	Sperry Flt Sys Phoenix, Arizona	Steve Kush 602-869-1622	80-C-0029	8 Aug 80 / 8 Feb 82
4 ΔP Transducer	Teledyne Ryan Elec San Diego, Calif.	Howard J. Malan 714-291-7311 X671	80-C-0031	4 Aug 80 / 4 Feb 82
	Bertea Irvine, Calif.	Ron Cass 714-833-1424	80-C-0030	4 Aug 80 / 4 Feb 82
5 Optical Servovalve	Bertea Irvine, Calif.	Ron Cass 714-833-1424	80-C-0043	30 Sep 80 / 30 Mar 82
	Sperry Flt Sys Phoenix, Arizona	Steve Kush 602-869-1622	80-C-0042	26 Sep 80 / 26 Mar 82
6 Advanced Cockpit Controls/AFCS	TBA			

ADOCS ELEMENT:
ADVANCED COCKPIT CONTROLS/ADVANCED FLIGHT CONTROL SYSTEM

HIGH PILOT WORKLOAD ⇒ COMPLEX SCAS ⇒ FBW

FBW ALLOWS:

- MULTI-MODE SCAS
- GAIN SCHEDULE
- HIGH AUTHORITY/GAIN
- SIDE ARM CONTROLLER



FBW CONCERNS:

- SAFETY
- R & M
- VULNERABILITY

D-315 ADOCS

ADVANCED COCKPIT CONTROLS/FCS ELEMENT
(AEROMECHANICS LABORATORY)

OBJECTIVES

- DESIGN CRITERIA FOR:
  - INTEGRATED SIDE STICK CONTROLLER
  - STABILITY AND CONTROL AUGMENTATION
  - DISPLAY – VISION AID SYMBOLOGY
  - SENSORS
  - DIGITAL FLIGHT CONTROL LAWS

APPROACH

- CONTRACTED STUDY
  - ANALYSIS
  - SIMULATION (AMES GROUND-BASED FACILITIES)
- IN-HOUSE SUPPORT

ACCOMPLISHMENTS IN FY 80

- STATEMENT OF WORK DEVELOPED AND REVIEWED
- PRELIMINARY INVESTIGATION OF 2 AXIS DISPLACEMENTS SSC

PLANS FOR FY 81

- INITIATE CONTRACTED EFFORTS
- PERFORM IN-HOUSE ASSESSMENT OF SSC
- SUPPORT CONTRACTOR DEVELOPED SIMULATIONS

PRESENTATION AND TEXT BY

TED CARTER
DIRECTOR OF TECHNOLOGY
SIKORSKY AIRCRAFT

AVIONICS, HUMAN FACTORS & CONTROL NEEDS

HAA/NASA Workshop

E. S. Carter

The tremendous advances being made in Avionics, Control and Human Factors makes this a particularly fruitful area for NASA rotorcraft research. Traditionally, helicopters have always taken considerable advantage of the use of electronics for stability augmentation and mission enhancing devices (particularly for the military). Now with the attention being given to digital techniques, large scale integrated circuits, electro optics and advanced control algorithms, the possibilities are almost limitless. This discussion will attempt to provide a check off of the major opportunities that should be addressed and then will focus on a few which are either directly related to mission needs discussed by the operators or to newer suggestions that haven't had much attention so far.

IFR Capabilities

There are three areas that should be addressed to improve our current en route IFR capabilities. First, we need to develop a technology to operate at low speeds down to a hover on the back side of the power curve safely and comfortably under IFR conditions. This will require improved low speed airspeed sensing and sideslip, means for displaying this information and control augmentation feedbacks that will allow accurate command of airspeed in the low speed regime.

Secondly, we need to improve our ability to carry external loads safely and with reasonable pilot workload under IFR conditions to allow external lift missions to penetrate overcast or at least launch with the risk of having to do so. It would appear that the load stabilization systems that have already been demonstrated for military external lift might well enhance this capability and it is suggested that an operational evaluation of such a device for IFR work should be conducted.

Thirdly, better technology for dedicated airways is urgently needed to provide helicopters with more flexibility than they now enjoy to operate independently of fixed wing traffic control and to provide this capability with a greatly increased population of rotorcraft in the system. Towards this end, we need to nail down the best options for low altitude navigation systems and establish when and where GPS fits into the civil picture and we also need to evaluate the self contained collision avoidance systems currently under development to establish their applicability to rotorcraft.

The other major area for improved IFR capability is terminal approach technology. In this area, several levels of capability need to be developed and demonstrated. First, we need a self contained precision approach capability for at least CAT I conditions, which can use weather radar with a ground based transponder, or eventually GPS. Secondly, we need a CAT II manual approach for a steep gradient curvilinear glide path based on MLS and thirdly, a CAT III autoland steep gradient, curvilinear MLS capability. Once the work already initiated on this has been nailed down, it should be extended to provide a 4D capability so that rotorcraft can operate with the very high degree of air space utilization efficiency that their speed flexibility should allow. The ground work for all of this technology is well in hand: it remains to demonstrate it and seek opportunities for operational evaluation.

Safety Enhancement and Pilot Workload Reduction

There are many opportunities to apply avionic technology to increase safety and reduce pilot workload. Better redundancy management concepts which take advantage of distributed processing techniques and low cost LCI technology can dramatically increase the reliability which digital flight control systems can offer. But certification criteria and software validation technology is needed to support their use, along with technology to predict lightning/EMI effects and to protect therefrom.

A new area of attention for military aircraft has been sidearm controllers and they may well find a place for application to civil/industrial uses, particularly where precision tasks must be accomplished with maximum visibility. Although encouraging progress has been made on a 4-axis sidearm controller, there is still a need to develop criteria for optimum feel and to come up with a concept for pilot/copilot coordination using sidearm force sticks.

In the human factors area, studies are needed to establish how to best use the newly-developed audio advisory and command capabilities. Tremendous advances are being made by the fixed wing industry in the application of electro optic displays; how they can best be married to helicopter requirements for civil mission needs study.

The safety record of external lift missions suggests that there's a need to develop a better control criteria concerning the limitations and procedures that should be imposed on external lift missions. In particular, we need a better handle on horsepower margin requirements, control power margin requirements, and the means for the pilot to know where he stands in regard to such margins with a given load. Wire & obstacle avoidance also needs attention.

An opportunity for the application of active control that hasn't had much attention so far, is the possibility of using automatic devices to manage extreme emergencies for which it is difficult to train a pilot. Automatic pitch reduction devices for engine failures have been investigated, but have never worked out because of the need to take into account the flight condition under which the engine failure occurs. Now with microprocessors, and more reliable sensors, it should be possible to use algorithms related to altitude and airspeed to command the optimum collective correction incase of an engine failure. Emergency water ditchings at night or under IFR conditions is another task which probably could be done better automatically than by the average pilot. Tail rotor drive failures can be significantly mitigated if the tail rotor can be put into autorotation, but this again requires almost instantaneous diagnosis and immediate corrective action, which a microprocessor may be better taught to accomplish. As we consider higher harmonic control for vibration reduction, we should also investigate the potential of using 1 per rev control to compensate for main rotor blade damage or even partial loss of a blade. (Such a device might even serve the function of providing an automatic tracking capability and at the same time, provide a sensitive means for identifying any degradation of a given blades' characteristics.)

Ride Quality Improvement

With regard to ride quality improvement, we need human factor studies to establish what ride qualities requirements really are for a working passenger. As missions are extended and as we come to depend more on the executive or business commuter, it will be increasingly important to provide the same type of working environment a business passenger enjoys on a jet transport. How this translates into vibration, turbulence susceptibility, and internal noise criteria is so far an unexplored human factors problem; previous ride quality juries have generally focused on the sight-seeing tourist type of passenger.

Once the requirement is established, avionic active control via higher harmonic control techniques and automatic gust suppression devices can undoubtedly provide major improvements over the ride quality currently able to offer. The ultimate goal, of course, is to provide an environment competitive with the high altitude commercial aircraft of today.

Technology For More Cost Effective Design

There are also many ways that active control technology and better understanding of human factor requirements can provide cheaper, lighter, more reliable, generally more cost effective, control systems. Empennage are a particularly troublesome liability to helicopters in many flight conditions, so the application of relaxed longitudinal stability concepts beyond that already exploited by rotorcraft, could reduce low speed transition problems and avoid complex stabilator solutions. We need first to establish the degree of inherent instability which automatic control systems can cope with in normal flight and which pilots will be able to tolerate under degraded conditions. Then concept demonstrations of minimum empennage solutions will be in order.

Recent experience with newer engines with improved transient response, is showing that the independent development of fuel controls and flight controls has its limitations: the technology to develop a totally integrated engine/flight control package to optimize the manner in which they work together to minimize droop & SFC while maximizing stability needs to be demonstrated.

Even at this late date, there remains several areas of design criteria where there's evidence to suggest that existing or proposed standards are, or will, unnecessarily penalize design. Principal areas for study are 1) the need for a positive stick gradient with air speed, 2) yaw control power requirements, especially for aircraft with very little or no weathercock stability, and 3) unalerted pilot reaction time which must be considered in response to emergencies such as engine failures and automatic control malfunctions.

Technology to Expedite Control System Development

There are also technology opportunities to reduce the risk and cost of development of advanced flight control systems. Currently mathematical models of rotor systems appear to be deficient in predicting high gain stability boundaries so a data bank of dynamic derivatives in both model and full scale, should be developed to provide a basis for correlation of these math models and to guide their development. In all probability, this will lead to the need for a better mathematical treatment of the dynamic inflow. Rotor empennage interaction phenomena are also an area where designers are frequently unable to predict the flight characteristics until their program is in trouble. Virtually every major recent helicopter program has had to undertake high cost flight development studies to iron out this sort of problem.

NASA has done a large number of studies on simulation fidelity requirements, procedures for simulation validation and parameter identification from flight data, but the technology has never been digested into a format that is truly useful for industry application. This is a prosaic, but nevertheless essential step, which NASA must undertake to make their past efforts truly of value.

A special case of control system risk reduction has to do with certification criteria. NASA should work closely with the FAA in establishing certification criteria for all of the new design concepts discussed in the preceding sections, and more particularly, to attack the question of how simulation may be used to complement flight test in the certification process. A start has been made on this latter subject, but apparently the effort is currently in limbo.

Mission Enhancement and Extension

Finally, there are a number of areas where the more sophisticated application of avionics and automatic control can provide capabilities for more efficient or extended civil missions. In many cases, these have their counterparts in military missions so that a single development effort could usefully respond to both civil and military requirements. An example might be, for instance, the development of a precision navigation and automatic control system for crop dusting which could apply equally to the mine counter measure mission, since both missions have the need for efficient coverage with minimum overlaps and no gaps. Another example is precision hover devices which will expedite the accurate placing of external loads. The Army HLH program some years ago developed hardware which showed tremendous performance advantage. A light weight, low cost alternate to the system demonstrated should be put together and evaluated under operational conditions. A practical means for viewing external loads from the cockpit is also an as yet unsolved problem.

Perhaps the most significant way that avionics could extend the capabilities of current helicopters would be to develop the technology for the safe and reliable harnessing of two or more helicopters to the same payload. This will be discussed in greater detail in the heavy lift session of the workshop, but to briefly summarize: a capability of carrying a 20-ton payload with two 10-ton helicopters has been demonstrated in a manual mode for air taxi operations, but pilot workload was too high to undertake forward flight operations. A master-slave concept has been proposed which should allow for reducing this capability to a practical reality in the same manner that automatic control has made the night and IFR sonar mission practical. With the great advances made in digital flight controls systems in recent years, this problem should be very straightforward and a NASA demonstration of the capability would be most timely.

AVIONICS & CONTROL TECHNOLOGY NEEDS

HAA/NASA WORKSHOP

DECEMBER 4, 1980

E. S. CARTER

SIKORSKY AIRCRAFT

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

IMPROVED IFR ENROUTE

- LOW SPEED IFR FLIGHT
  - TO A HOVER
  - CONTROLLED SIDESLIP
- EXTERNAL LIFT IFR
- DEDICATED AIRWAYS
  - LOW ALTITUDE NAVIGATION
  - SELF CONTAINED COLLISION AVOIDANCE
- REMOTE AREA OBSTACLE/WIRE AVOIDANCE

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

ROTORCRAFT NEEDS FOR AVIONICS/CONTROL/HUMAN FACTORS R&D

- IMPROVED IFR CAPABILITY
  - ENROUTE
  - TERMINAL
- REDUCED PILOT WORKLOAD - INCREASED SAFETY
- RIDE QUALITY IMPROVEMENT
- MORE EFFICIENT DESIGN (LIGHTER, CHEAPER, BETTER R/M)
- REDUCED DEVELOPMENT COST RISK
- ENHANCED MISSION CAPABILITY

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

IMPROVED IFR:

TERMINAL APPROACH

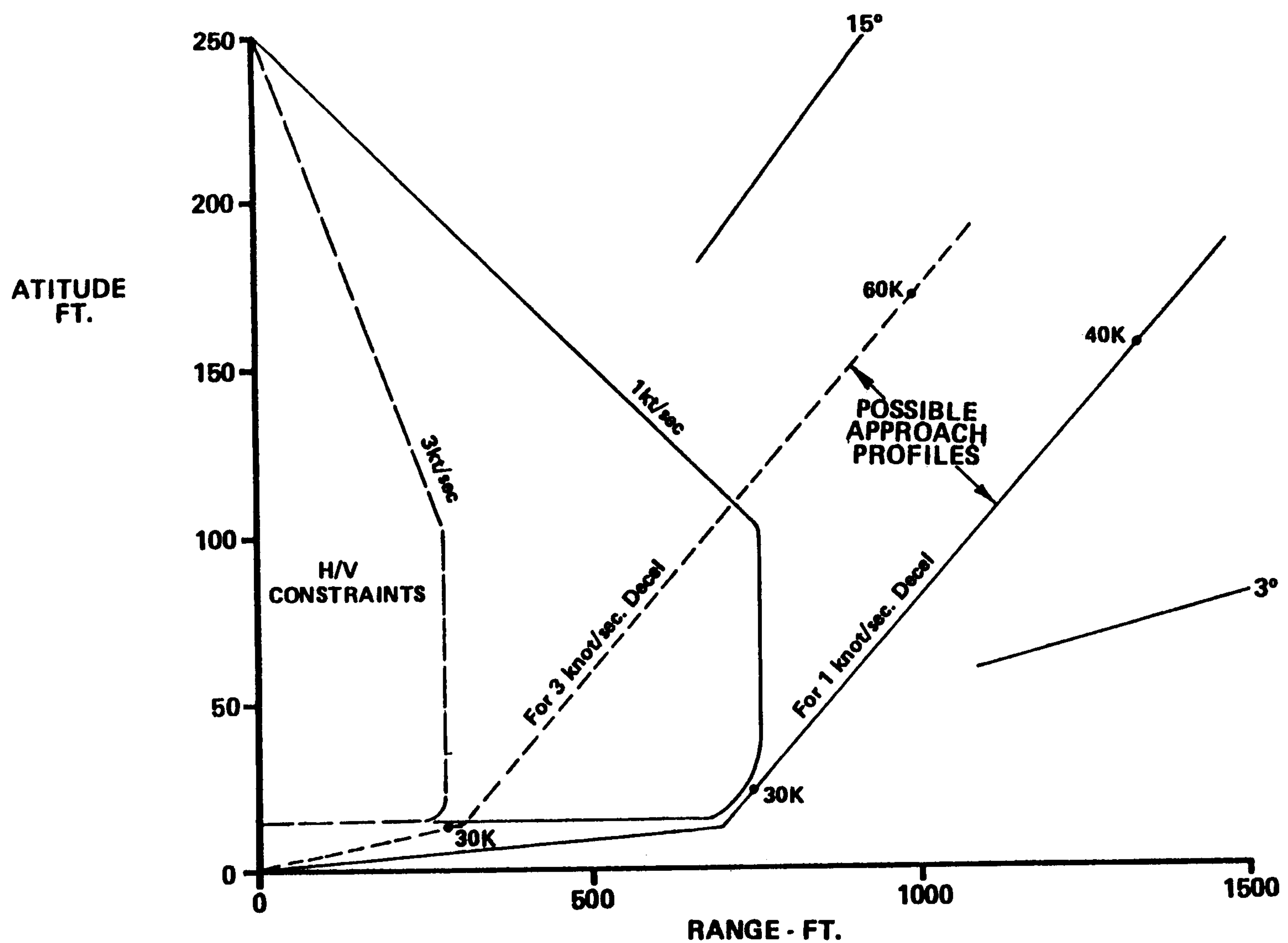
- SELF CONTAINED PRECISION APPROACH
  - WEATHER RADAR
  - GPS

  AT LEAST CAT I

- CAT II MANUAL APPROACH - MLS - STEEP GRADIENT
- CAT III AUTOLAND APPROACH - MLS - STEEP GRADIENT
- 4D AUTOLAND - MLS
- SHIPBOARD LANDING - COAST GUARD

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

SPEED APPROACH PROFILE CONSIDERATIONS



INCREASED SAFETY - REDUCED PILOT WORKLOAD

- Redundancy Management Concepts
  - And Certification Criteria Thereof
- Side Arm Controllers
  - Feel Criteria
  - Pilot/Copilot Coordination
- Options for Pilot Info - Aircraft Control
  - Audio - Visual - Tactile
- Electro Optic Displays

Enhance Cockpit Visibility

- External Lift Limitations & Procedures
  - Horsepower Margins
  - Control Power Margins
- Emergency Management with Active Control

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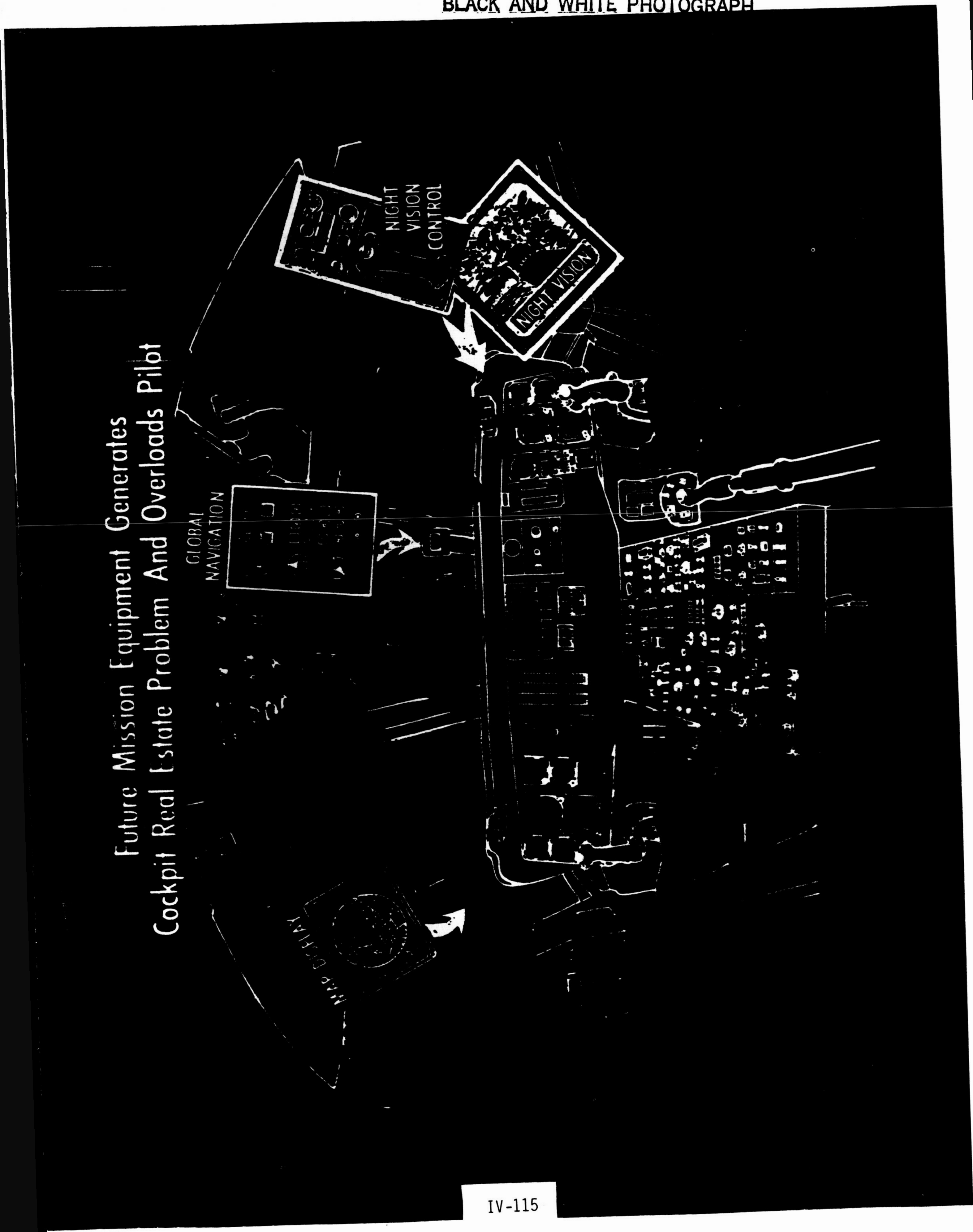
FOUR AXIS SIDEARM CONTROLLER


Future Mission Equipment Generates
Cockpit Real Estate Problem And Overloads Pilot
NIGHT VISION CONTROL
NIGHT VISION
GLOBAL NAVIGATION
MAP DISPLAY

ACT APPLICATIONS TO EMERGENCIES

- ENGINE FAILURE TRANSIENT MANAGEMENT
- AUTOMATIC IFR/NIGHT ENGINE OUT DITCHING
- TAIL ROTOR MALFUNCTION MANAGEMENT
- ONE PER REV CONTROL TO COUNTER BLADE DAMAGE

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

RIDE QUALITY IMPROVEMENTS

- CRITERIA STUDIES OF RIDE QUALITY REQUIREMENTS FOR THE WORKING PASSENGER

- HIGHER HARMONIC CONTROL

- GUST SUPPRESSION FEEDBACK/DEVICES

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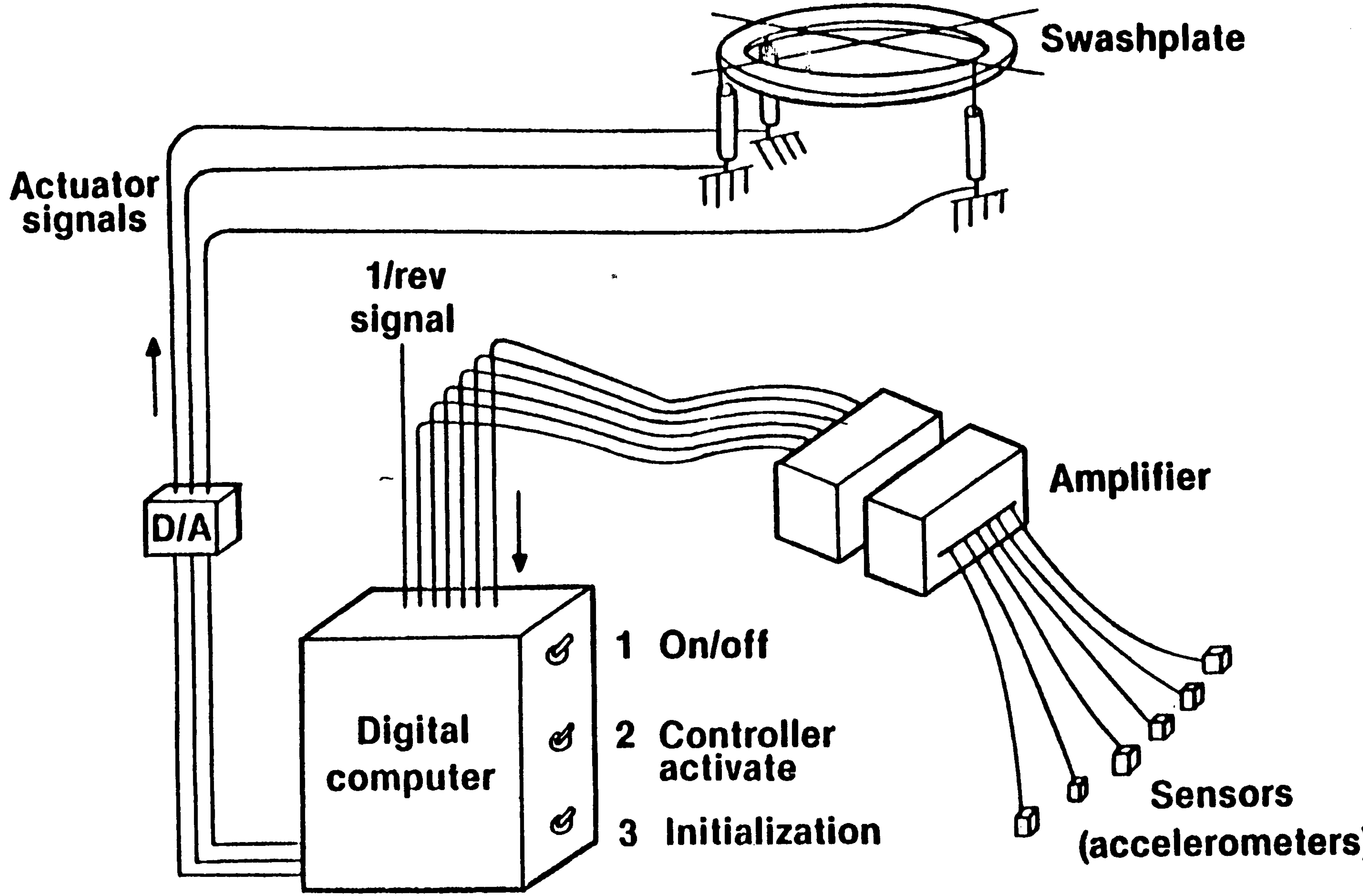
HIGHER HARMONIC CONTROL CONCEPT



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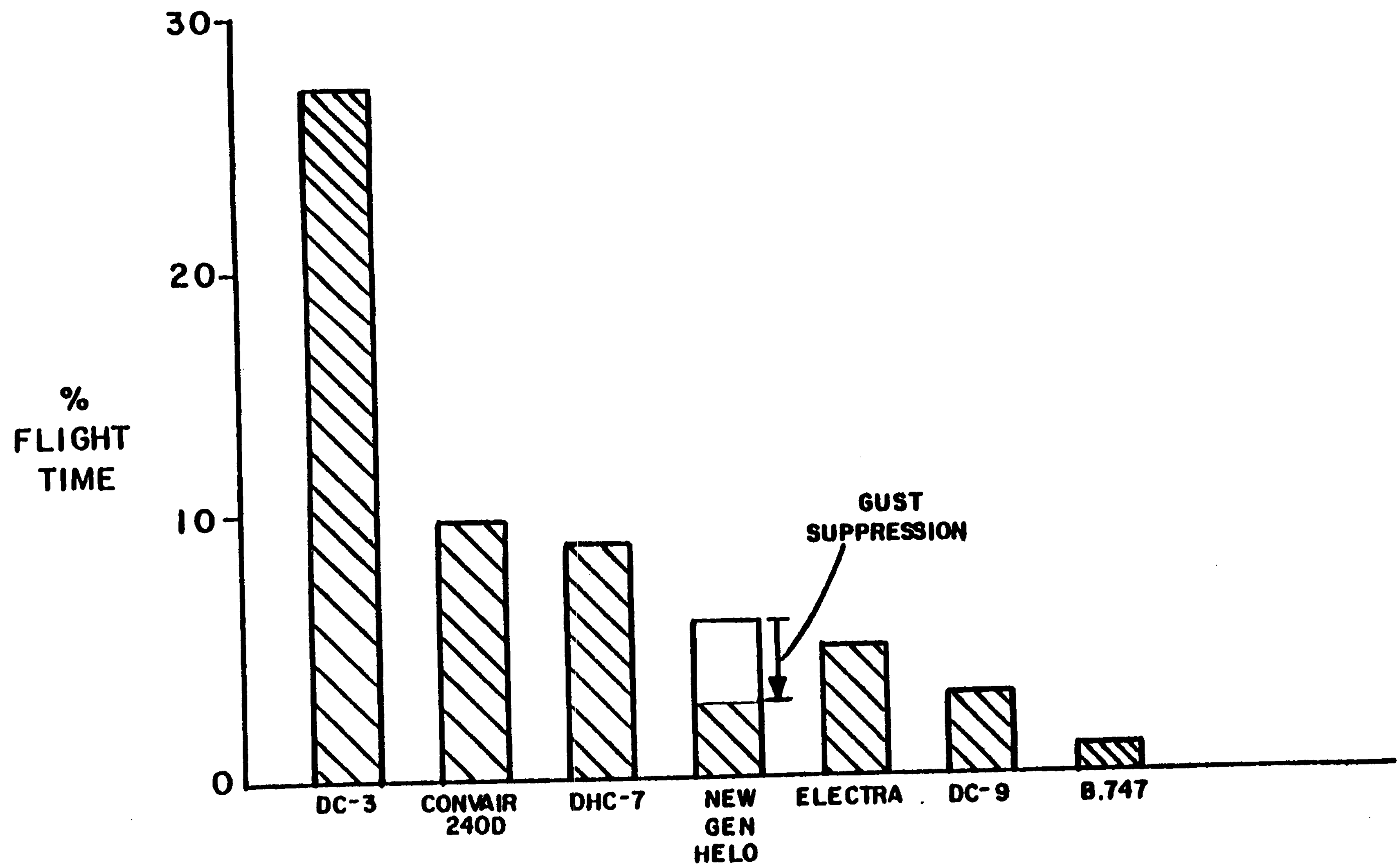
RELATIVE EXPOSURE TO NORMAL ACCELERATION >0.5G

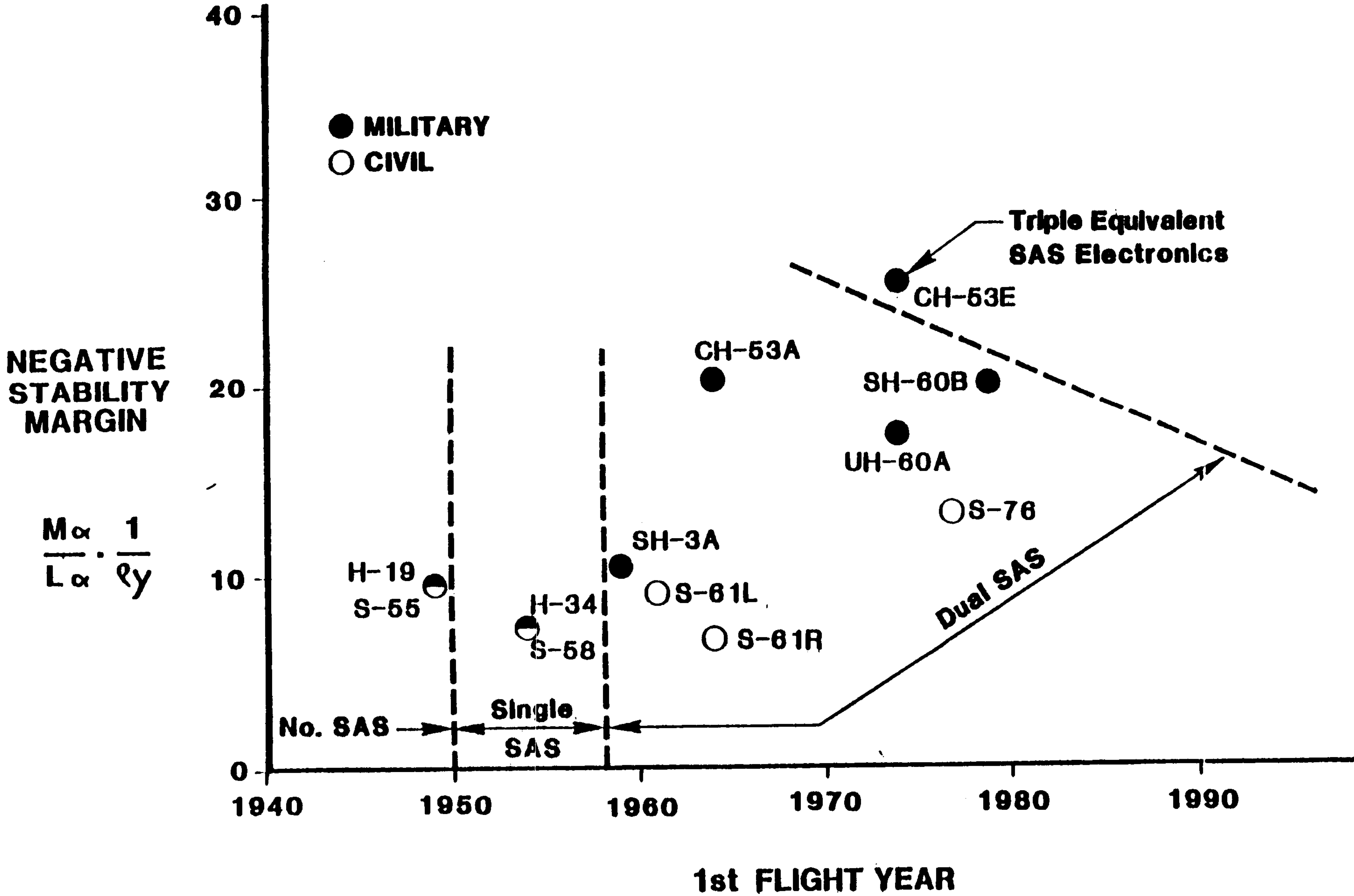


MORE EFFICIENT DESIGN CONCEPTS

- RELAXED LONGITUDINAL STABILITY
  - MAX TOLERABLE
  - CONCEPT DEMONSTRATION
- INTEGRATED ENGINE/FLIGHT CONTROL
  - MINIMUM DROOP
  - MAXIMUM STABILITY
  - OPTIMUM SFC
- REEXAMINE CRITERIA FOR
  - STICK GRADIENT
  - YAW CONTROL POWER VS WEATHERCOCK STABILITY
  - UNALERTED PILOT REACTION TIME

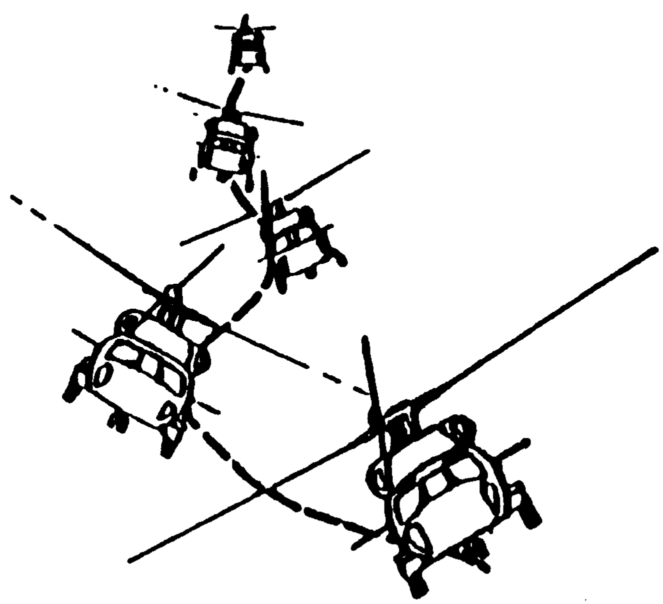
SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

HELICOPTER STABILITY RELAXATION TRENDS

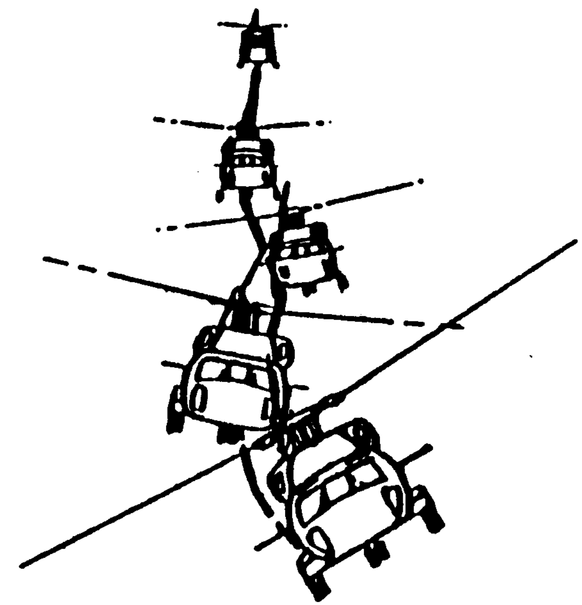


CLASSIC AIRPLANE DUTCH ROLL

INFLUENCED BY FUEL MANAGEMENT DYNAMICS



Adverse Fuel Control Coupling



Zero Fuel Control Interactions

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CONTROL GRADIENTS SHOULD FOCUS ON FORCE NOT POSITION

(THE PRICE FOR A POSITIVE STICK POSITION GRADIENT IN A HELICOPTER IS TOO HIGH)

- CONTROL SYSTEM
  - APPROXIMATELY 30% INCREASE IN UPSTREAM CONTROL TRAVEL
  - GENERALLY WILL REQUIRE SECOND SET OF STOPS, DOWNSTREAM
  - ADDITIONAL ACTUATOR, AND ASSOCIATED LINKAGES
  - ADDED ELECTRONICS, CIRCUIT BREAKERS, ETC.
- OPERATIONAL
  - ADDED RIGGING COMPLICATION
  - ADDED FAILURE MODE WHICH MUST BE CONSIDERED
- COCKPIT
  - FORCES SEAT FURTHER FROM INSTRUMENT PANEL
  - COMPROMISED OUTSIDE VISIBILITY
  - CREATES AN UNCOMFORTABLE PILOT PHYSICAL POSITION

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

TECHNOLOGY TO REDUCE DEVELOPMENT COST/RISK

- EXPLAIN HIGH GAIN STABILITY BOUNDARIES
  - DYNAMIC DERIVATIVE CORRELATION
  - DYNAMIC INFLOW MODELING
- ROTOR/EMPENNAGE INTERACTION
- SIMULATION FIDELITY REQUIREMENT COOKBOOK
- PROCEDURE FOR SIMULATION VALIDATION
- PARAMETER IDENTIFICATION COOKBOOK
- CERTIFICATION CRITERIA FOR ALL DESIGN CONCEPTS DISCUSSED ABOVE
- SIMULATION TECHNOLOGY TO SUPPORT CERTIFICATION
- LIGHTNING/EMI TOLERANCE
  - PROTECTION
  - PREDICTION

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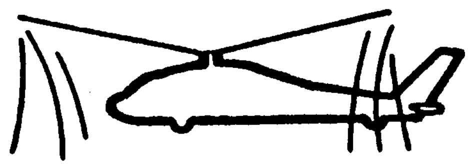
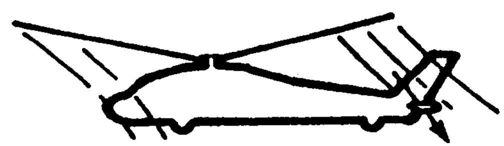
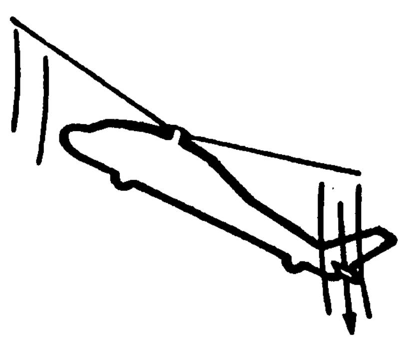
Helicopter Empennage Present Special Problems



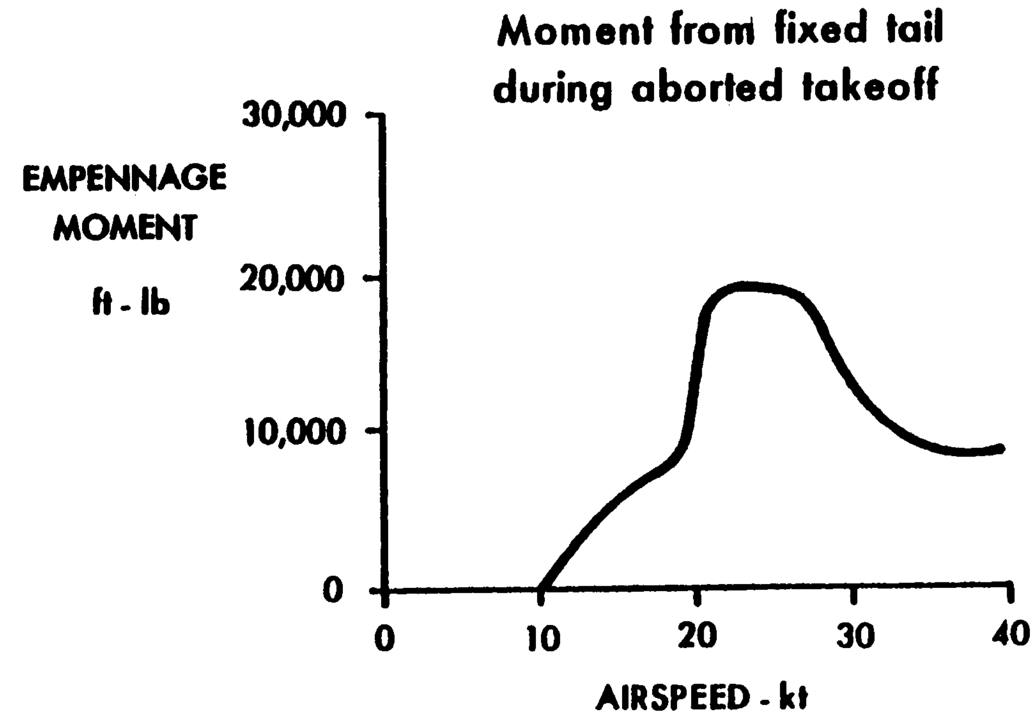
Hover



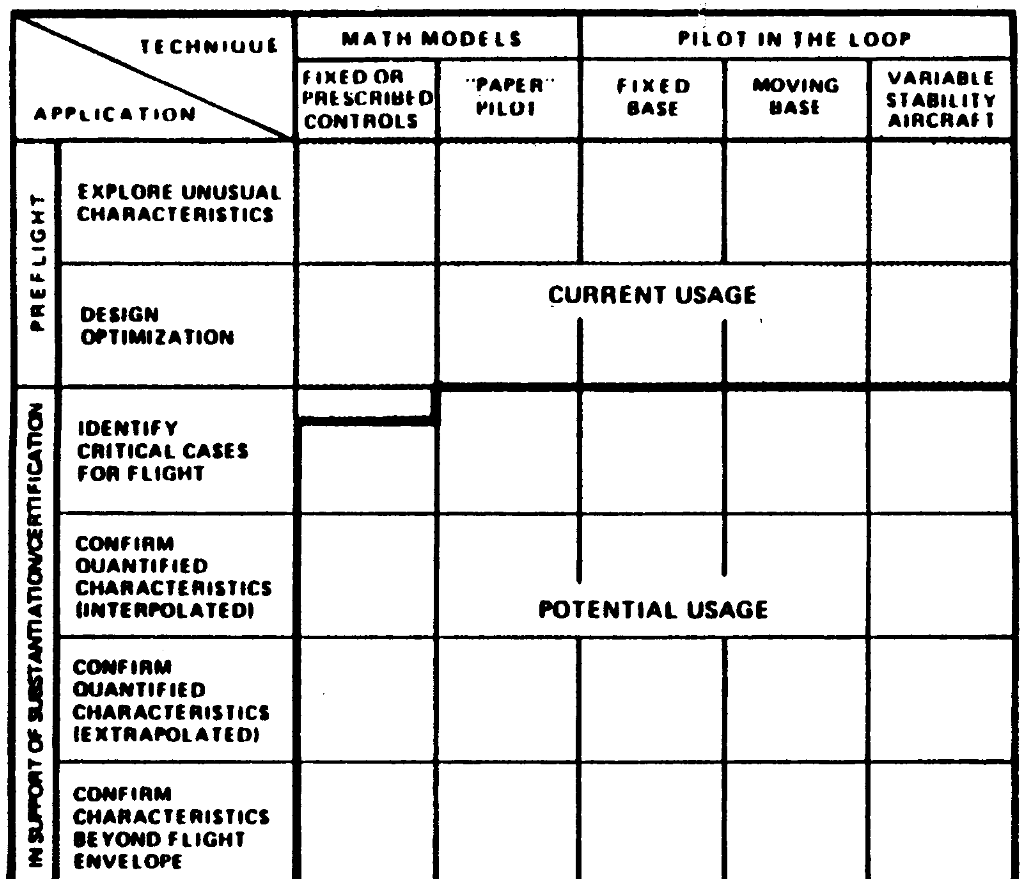
Low Speed



Low Speed Flare



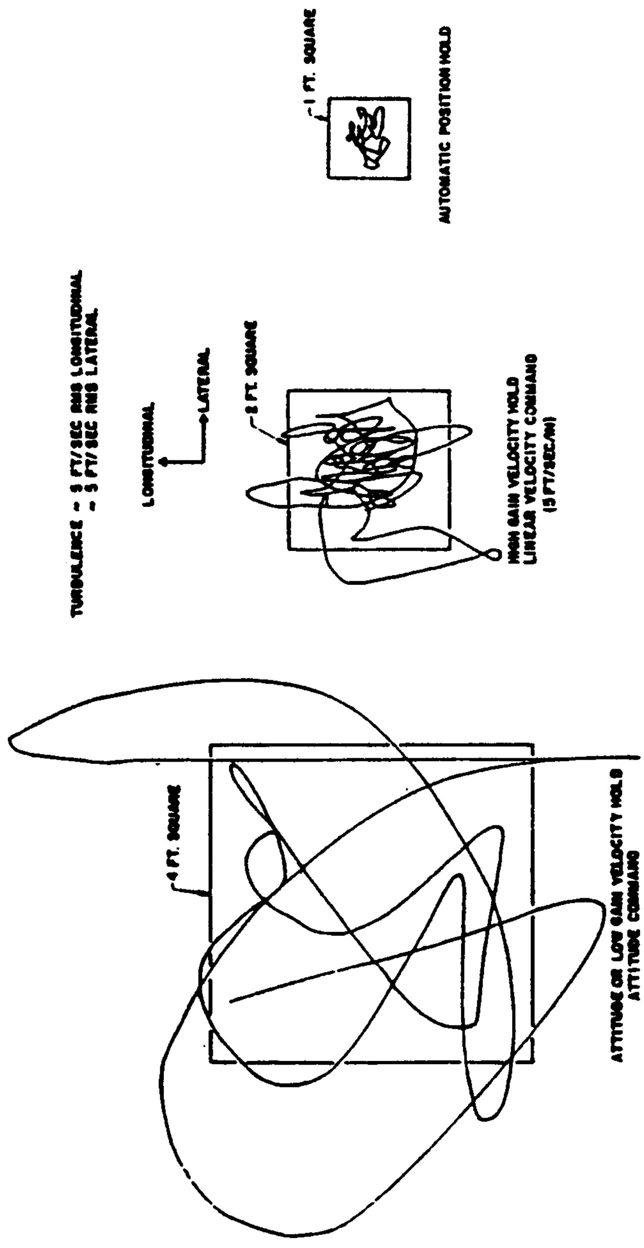
SIMULATION TECHNIQUES

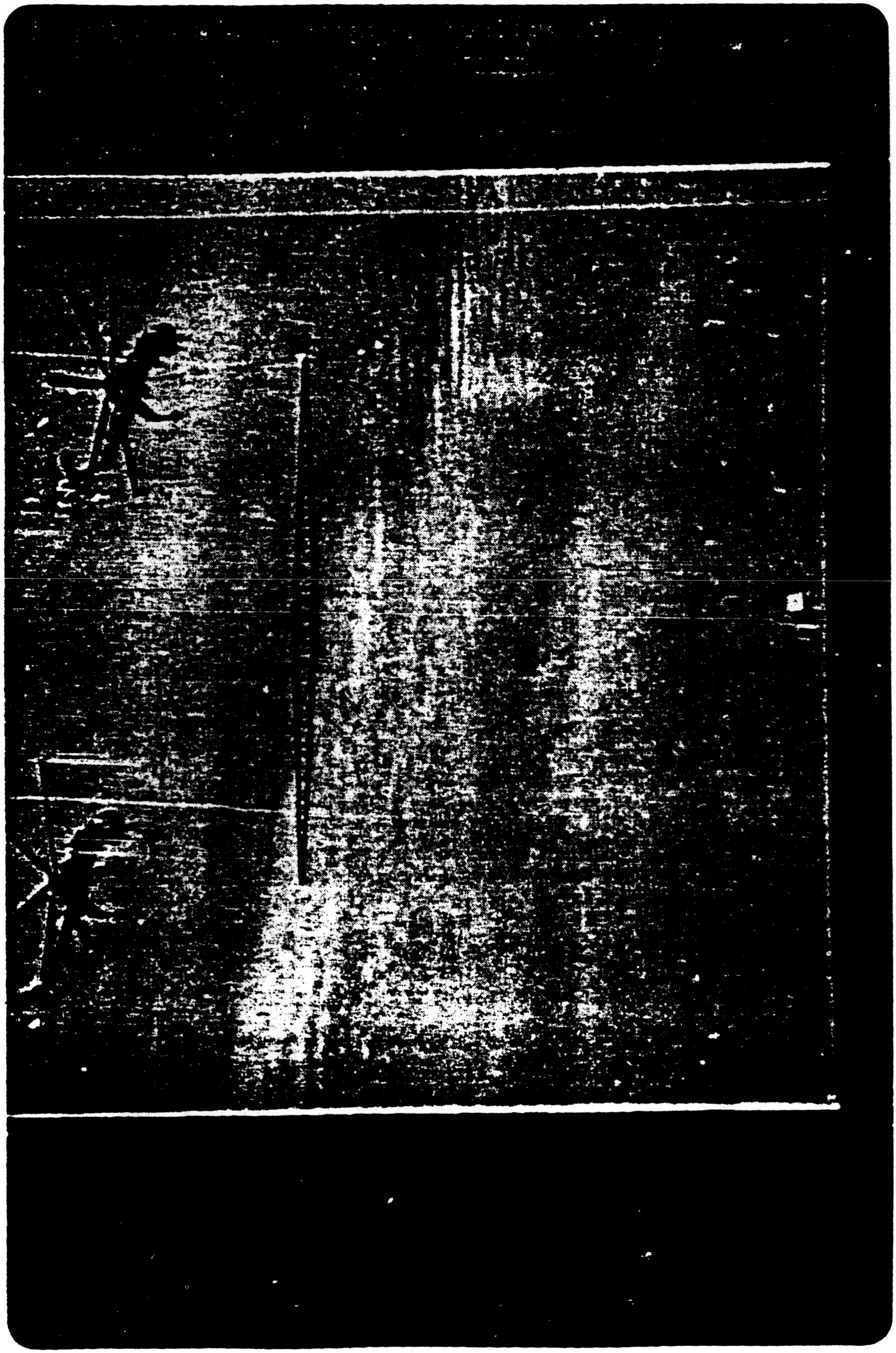


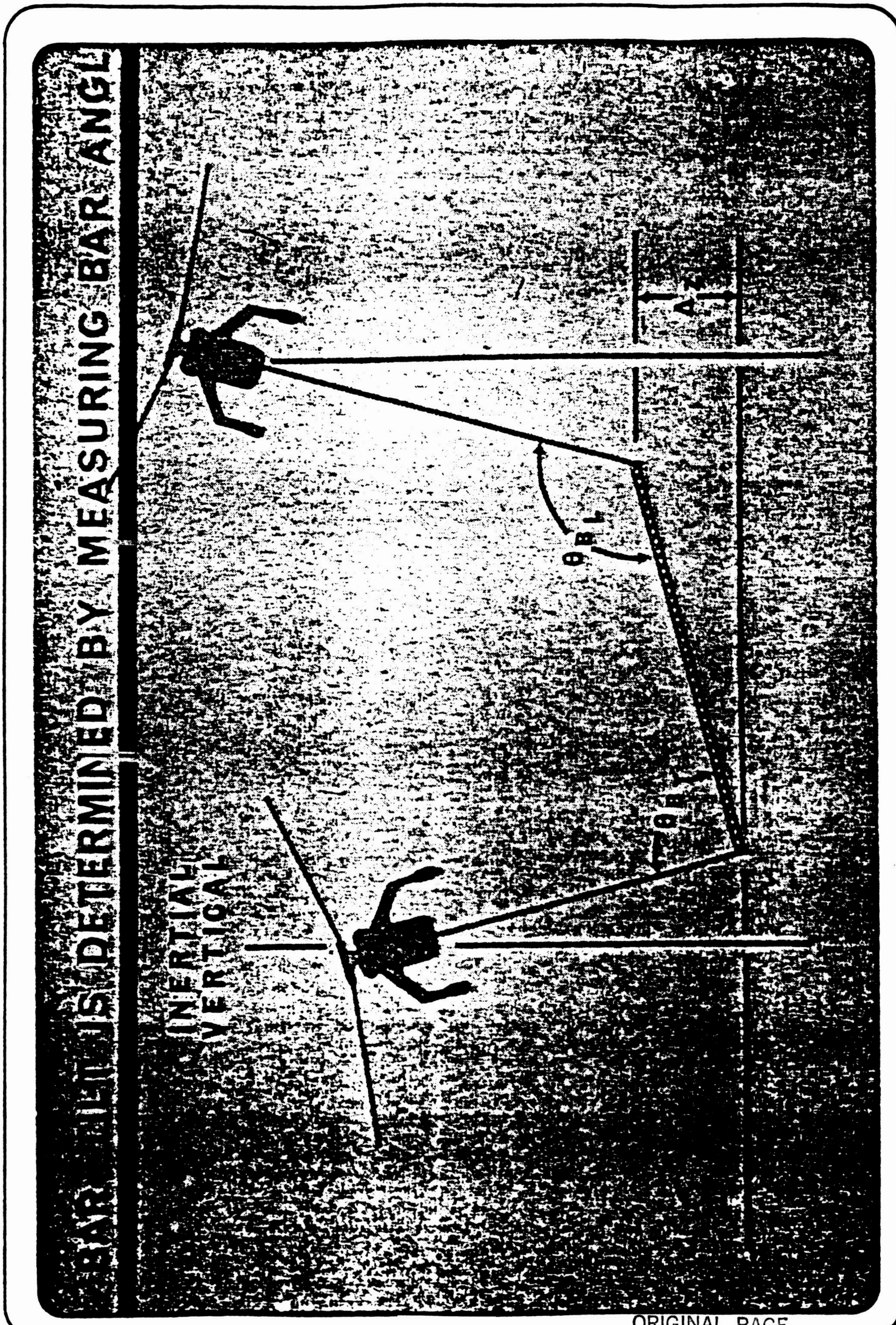
ENHANCED MISSION CAPABILITY

- PRECISION NAVIGATION FOR CROP DUSTING
  - APPLY MCM TECHNOLOGY
- PRECISION HOVER
  - OP EVAL OF LIGHT WEIGHT SYSTEM
- TWIN LIFT
  - MASTER SLAVE DEMO & OP EVAL

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES


TURBULENCE – 3 FT/SEC RMS LONGITUDINAL
– 3 FT/SEC RMS LATERAL
LONGITUDINAL
LATERAL
1 FT. SQUARE
AUTOMATIC POSITION HOLD
2 FT. SQUARE
HIGH GAIN VELOCITY HOLD
LINEAR VELOCITY COMMAND
(5 FT/SEC/IN)
4 FT. SQUARE
ATTITUDE OR LOW GAIN VELOCITY HOLD
ATTITUDE COMMAND





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VOLUME IV

APPENDIX C

ALL WEATHER OPERATIONS SUBSESSION

MANUFACTURERS PRESENTATIONS

* KEN McELREATH - COLLINS RADIO
* PAUL PENCIKOWSKI - HUGHES HELICOPTERS
* RICHARD CNOSSEN - MAGNAVOX
* LARRY CLARK - HELIFLIGHT SYSTEMS

POINTS* MADE BY MC ELREATH

(Presentation material not available at this date.)

KENNETH MC ELREATH

SYSTEMS ENGINEER - FLIGHT CONTROLS & DISPLAYS

ROCKWELL COLLINS

1. Standardize IFR certification criteria.
2. Area navigation approach aids.
3. Cockpit display symbology.
4. Airframe and rotor design.

POINTS* MADE BY PENCIKOWSKI

(Presentation material not available at this date.)

PAUL PENCIKOWSKI

DIRECTOR - ADVANCED CREW STATION DESIGN

HUGHES HELICOPTERS

1. Accidents caused by faulty system design rather than pilot error.
2. Expanded use of CRT display.
3. Direct transmission display to pilot eye.
4. Improved control technology.

PRESENTATION AND TEXT BY

RICHARD CNOSSEN
ENGINEER SECTION MANAGER
MAGNAVOX

CIVIL HELICOPTER APPLICATIONS OF THE NAVSTAR GLOBAL POSITIONING SYSTEM (GPS)

Richard Cnossen
John D. Cardall
MAGNAVOX ADVANCED PRODUCTS AND SYSTEMS COMPANY
Torrance, California

ABSTRACT

GPS has the potential of satisfying world-wide and local civil air navigation requirements for Area Navigation (RNAV), Approaches and Landings, and Air Traffic Control (ATC). This paper discusses the GPS Program and its ideal navigation attributes. It describes the Phase I user equipment and summarizes field test results to date. It also describes a projected, low cost civil air GPS set, identifies several unique helicopter applications, and outlines technology effort required to realize the full potential of GPS for helicopters.

INTRODUCTION

GPS is a satellite-based, radio navigation system designed to provide global, all weather, 24-hour, accurate navigation to an unlimited number of authorized users. It is under development by the U.S. Department of Defense (DoD) and is scheduled to become fully operational in 1987. In the interim, a few GPS satellites provide world-wide signal coverage for several hours each day for test and development purposes as well as for any missions that can be scheduled around the availability of the signal.

Civil user access to operational GPS signals will be achieved via low cost, lightweight sets which will amply satisfy RNAV, approach and non-precision landing requirements and may satisfy category 3 landing requirements. Improved helicopter operations under increasingly congested urban conditions as well as at remote or unimproved locations will result. The next few years offer the opportunity to investigate and develop key capabilities, such as 4-D (3-dimensional, time referenced position) navigation, differential GPS for precision landings, and airborne sets optimized for helicopter use, as well as the operational doctrine needed to fully exploit GPS for civil helicopter applications.

CIVIL HELICOPTER NAVIGATION

An ideal navigation system for helicopters (as well as civil aviation in general) would have the following attributes as a minimum:

(1) global, all weather, day-night coverage without line-of-sight limitations;

(2) highly accurate 3-dimensional (3-D), time referenced navigation to support (a) narrow corridor routing with minimum separation distances and (b) landing and takeoff minimums which approach "precision" instrument approaches;

(3) independence from point reference navigation aids;

(4) non-saturable capacity;

(5) low user cost;

(6) easy adaptability to advanced Air Traffic Control (ATC).

Present navigation systems and their contemplated upgrades are limited with respect to these ideal attributes, particularly in area of coverage. Their limitations become more pronounced in view of the foreseeable need to extend coverage to a virtually unlimited number of landing/take-off areas for helicopters and to provide coverage for enroute flight under increasingly congested air space conditions. The only identifiable system which satisfies all of the ideal navigation system's requirements is the NAVSTAR Global Positioning System (GPS) currently under development by DOD.

GPS DESCRIPTION AND STATUS

GPS is a satellite based navigation system under development by DOD. It is designed to provide suitably equipped users with worldwide, continuous, highly accurate, 3-D navigation and time. GPS consists of three segments: the space segment, the ground control segment, and the user segment (Figure 1).

In the operational space segment, a constellation of 18 satellites will circle the earth in nominal 10,900 nautical-mile orbits with a period of 12 sidereal hours. The constellation will be configured in several 55^{o} inclined orbital planes with the objective of providing direct, line-of-sight navigation signals continuously from at least four satellites to any point on or near the surface of the earth. Each satellite transmits its navigation signals on two L-Band (UHF) frequencies.

The signals consist of a Precision (P) code and a Coarse Acquisition (C/A) code which are both pseudorandom digital

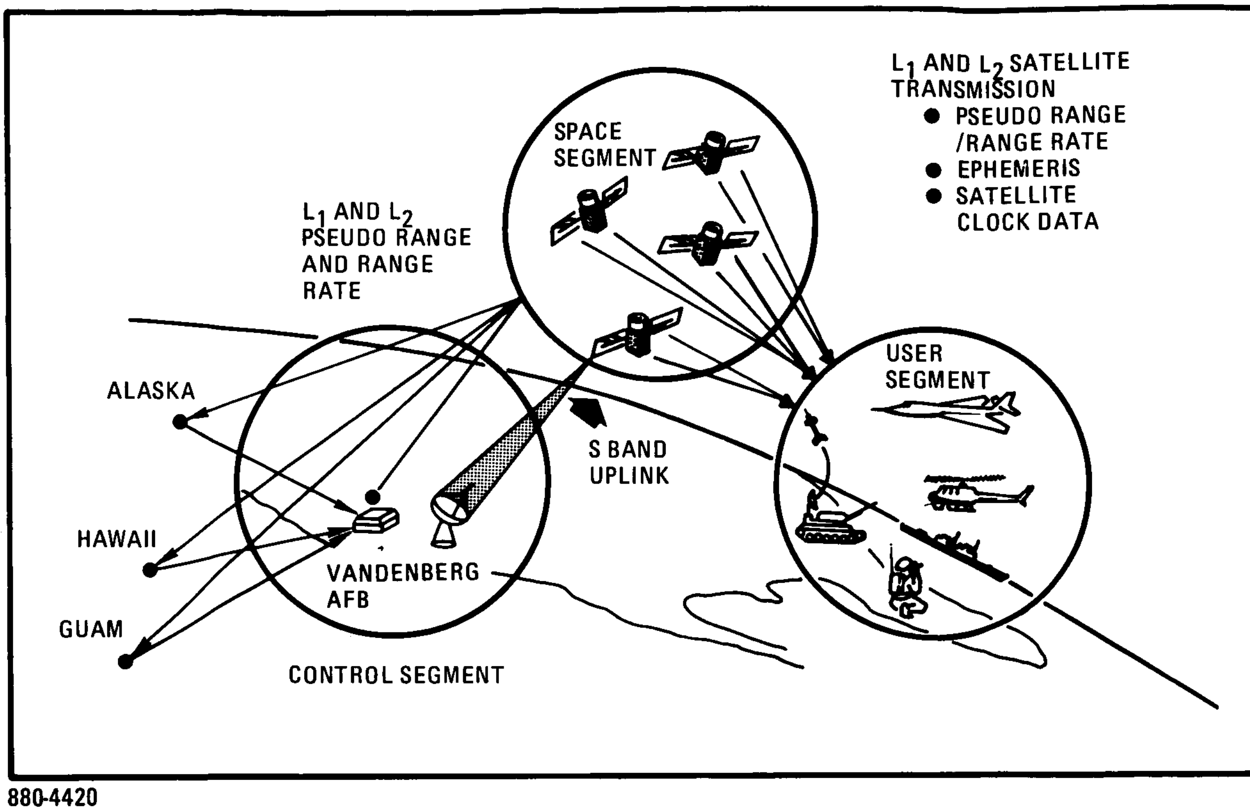

Figure 1. NAVSTAR GPS Segments

sequences used for ranging. The signals also contain a navigation message which provides satellite position, time, and atmospheric propagation correction data generated by the ground control segment. The two-frequency transmission permits users to correct for frequency sensitive propagation delays and anomalies.

The ground control segment has four monitor stations which are located at Guam, Hawaii, Alaska, and Vandenberg AFB in California. A Master Control Station is also located at Vandenberg. The monitor sites track the satellites via their broadcast signals as they come into view. The Master Control Station collects the tracking data and generates the navigation message for each satellite which is uploaded to each satellite's memory daily via S-Band telemetry link. In this way, the satellites are able to broadcast an accurate description of their position as a function of time.

The user segment consists of ground-based, marine, airborne, and spaceborne platforms equipped with a GPS receiver/processor capable of tracking four satellite signals either simultaneously or sequentially. Part of the task will be to select which four satellites to track to optimize accuracy as the satellites slowly pass by. Position is computed by making time-of-arrival (TOA) measurements on the P or C/A code transmitted from discrete satellite positions defined by the navigation message. Each set of four TOA measurements permits determination of the four independent variables of latitude, longitude, elevation, and user clock offset. Velocity is computed by making doppler measurements on the carrier frequency. Each set of four doppler measurements permits determination of the four independent variables of 3-D velocity and user clock drift. Navigation is accomplished via a Kalman filter which propagates a continuous navigation solution based on the TOA and doppler measurements. Use of the filter's propagation capability permits temporary operation on fewer than four satellites.

Full 3-D Operational capability with 18 satellites is expected by the end of 1987 with 2-D operational capability commencing at the end of '85. In the meanwhile, a five to six satellite constellation will be maintained for test and evaluation (see Figure 2).

PHASE I USER EQUIPMENT

As part of the Phase I Program, four types of user equipment were developed to demonstrate the navigation accuracy and other parameters of GPS. This development culminates eight to ten years of prior breadboarding, studies and demonstrations of 621B, TIMATION, and the Defense Navigation System Development Program. Field testing at the Yuma Test Range has been completed on four types of user equipment, designated the Set X, Set Y, Manpack and Set Z. These sets, de-

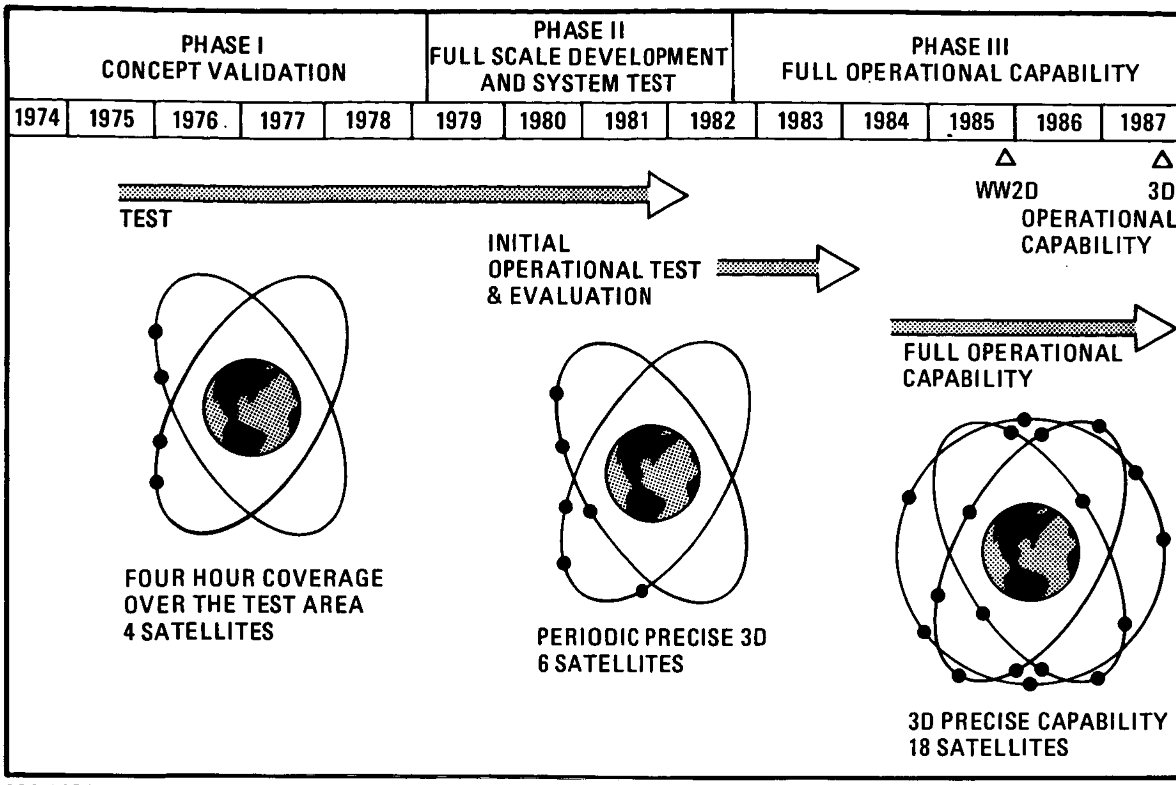

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Figure 2. Schedules and Orbital Configurations

TABLE 1. Phase I NAVSTAR User Sets

USER SET	CHARACTERISTICS	PLATFORM	FREQ.	CODE	CHANNELS
X	HIGH ACCURACY HIGH ACCURACY HIGH DYNAMICS FAST FIX	B-1, F-4 SUBMARINE	L_1/L_2	CA/P	4
Y	LOW DYNAMICS	SHIPS	L_1/L_2	CA/P	1
MP	SMALL LOW POWER	MANPACK VEHICLE	L_1/L_2	CA/P	1
Z	LOW COST LOW DYNAMICS	CIVIL USERS	L_1	CA	1

1180-7274

scribed in Table 1 are designed to satisfy performance requirements which may be operationally or platform unique in the future.

X-SET – The Continuous Set

Applications in which the dynamics are high, the expected jamming is severe and/or a fast fix is required call for a set that can track four satellites simultaneously to provide continuous navigation with position and velocity information. The X-set is designed to work with two antennas where shadowing is severe due to dynamics or where combined satellite and inverted range tests are desired. The set may be "aided" by an inertial platform to provide the ultimate in performance for GPS equipment.

Y-SET – The Sequential Set

The main differences between X and Y are in the receiver (4 carrier channels versus 1 carrier channel) and Navigation processor software associated with sequencing, alerting, etc. As a result, the Y-set contains less hardware than the X Set and is intended for users who will experience less dynamics and less jamming than the X user. Y also takes approximately 3 times longer to obtain a first fix and requires smaller position and velocity uncertainties. While X is the ultimate in performance, Y costs less.

MANPACK – The Small Set

Manpack was designed for small size (27 lbs.), low power (27 watts) and relatively low dynamics (30 m/sec). It supports a wide variety of Army and Marine Corp missions. Manpack contains a single channel sequencing receiver, operates with both C/A and P codes and resolves ionospheric uncertainties through the use of L_1 and L_2 frequencies. The user is able to navigate or position himself in either the Military Grid Reference System (MGRS) or local datum coordinates. He can display distance and azimuth to selected rendezvous locations with reference to true, grid or magnetic north.

Z-SET – The Low Cost Set

The Z-set is a low cost MIL-Spec Avionics navigator. It consists of a sequential receiver like Y, but operates only at the L_1 frequency and uses only the C/A code. To reach a design-to-cost goal as an avionics set required numerous interacting trade-offs of cost versus performance. Table 2 summarizes its performance capability with respect to the X sets.

The Z-set shown in Figure 3 is housed in a 3/4 ATR short. It weighs 34 pounds and requires 53 watts. The unit is put together in slices, much like the ARC-164 UHF-AM radio which was the first major design-to-cost military avionics program.

TABLE 2. Z-Set Trades Performance for Low Cost

GPS SET FEATURES	X	Z
PSEUDO RANGE MEASUREMENT ACCURACY (3σ) METERS	6	60
JAMMING VULNERABILITY	LOW	HIGH
NORMAL TIME TO FIRST FIX	2-3 MIN.	5-8 MIN.
CAPABLE OF INERTIAL AIDING	YES	NO

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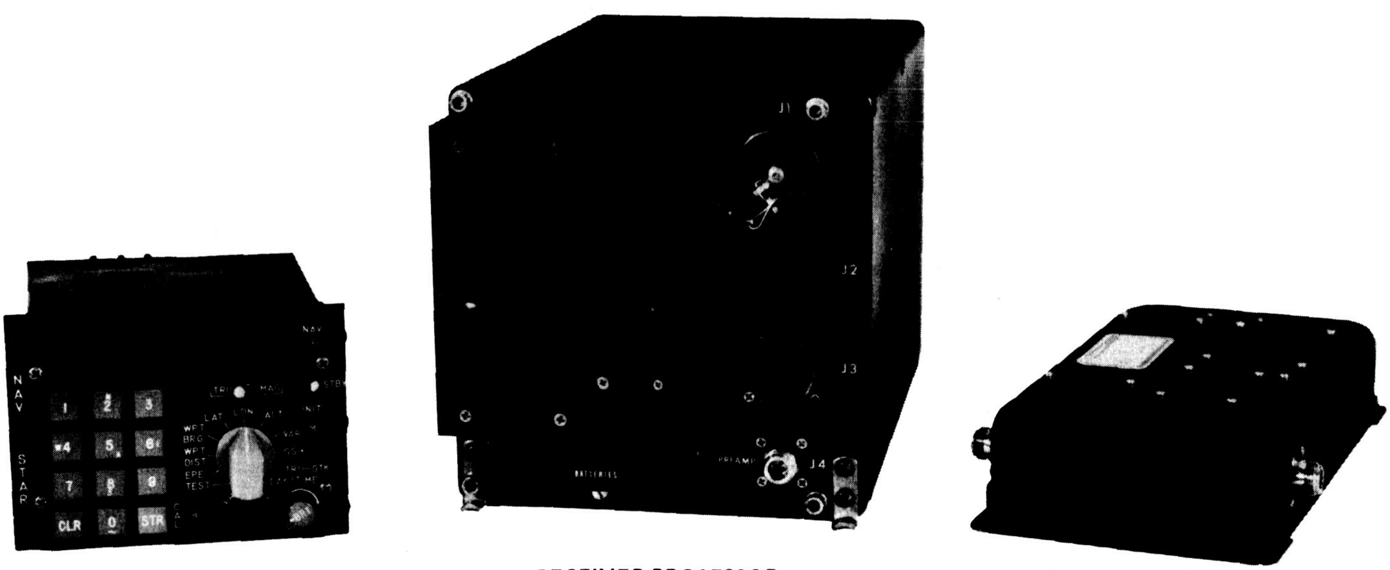

CONTROL INDICATOR

RECEIVER-PROCESSOR

RF AMPLIFIER

179-28

Figure 3. Z-Set Hardware Configuration

PHASE I FIELD TEST RESULTS

Navigation Accuracy

To date, GPS developmental Test and Evaluation has included over 700 field tests on 11 host vehicles with 7 types of GPS user equipment. Conducted over a period of two years, this extensive field test program addressed more than 20 major objectives ranging from system vulnerability to user applications. Test aircraft included a Navy F-4J, an Air Force C-141, a Navy P-3B, and an Army UH-1H.

Testing was conducted primarily at the U.S. Army Yuma Proving Ground and off the Southern California coast. Yuma's Precision Automated Tracking System, a computer-based laser tracking system, provided reference vehicle position for GPS accuracy determination at Yuma. Under most conditions the laser system provided position and velocity accuracies of 1 meter and 0.1 meter/sec., respectively.

Table 3 lists the 50th and 90th percentile values for three-dimensional system accuracies. The data represents a total of 76 missions conducted from November 1978 to April 1979.

TABLE 3. Field Test Results of User Equipment Navigation Accuracy

	POSITION ACCURACY (M)		VELOCITY ACCURACY (M/S)	
	50%	90%	50%	90%
FOUR CHANNEL IMU-AIDED SET	10	18	0.3	0.7
FOUR CHANNEL UNAIDED SET	10	16	0.6	2.5
SINGLE CHANNEL P CODE SET	14	27	1.4	3.7
SINGLE CHANNEL C/A CODE SET	16	37	0.7	3.7
MANPACK, STATIC	13	28	0.2	0.7

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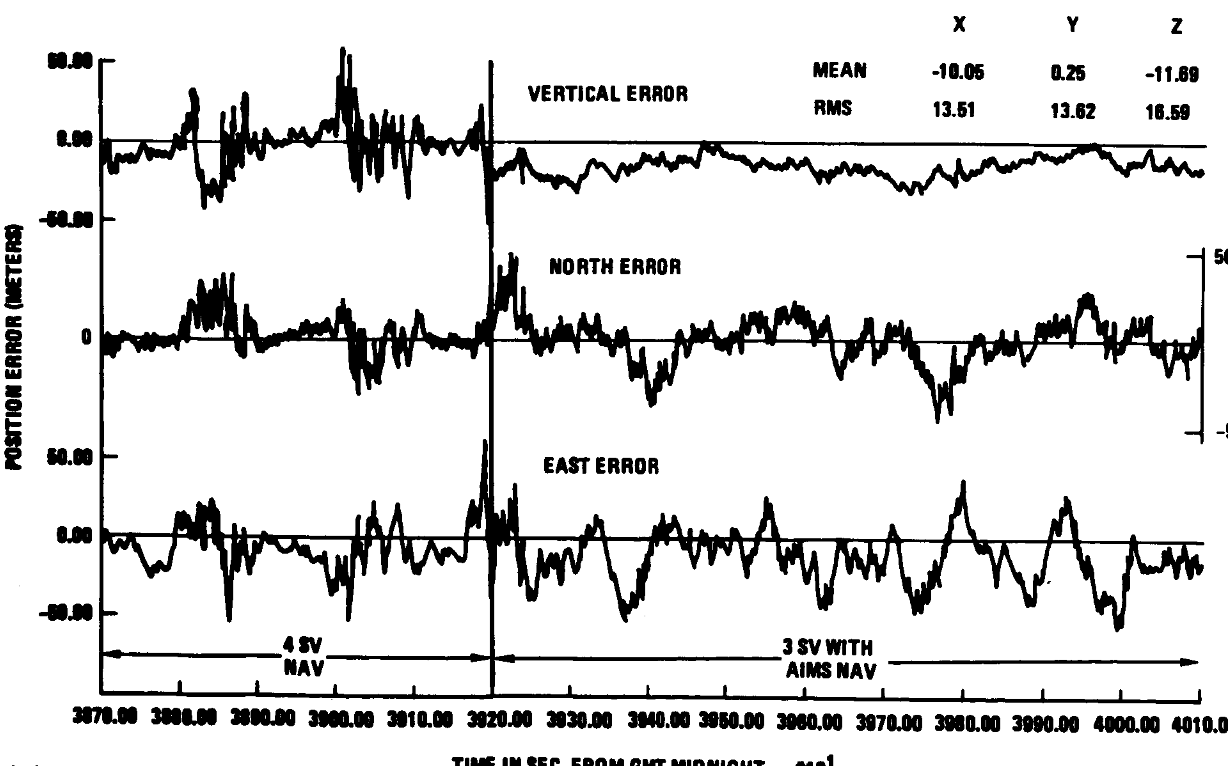

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Figure 4. Z-Set Field Test Results – Position Errors, April 4, 1979, C-141 Racetrack Course at Yuma, AZ.

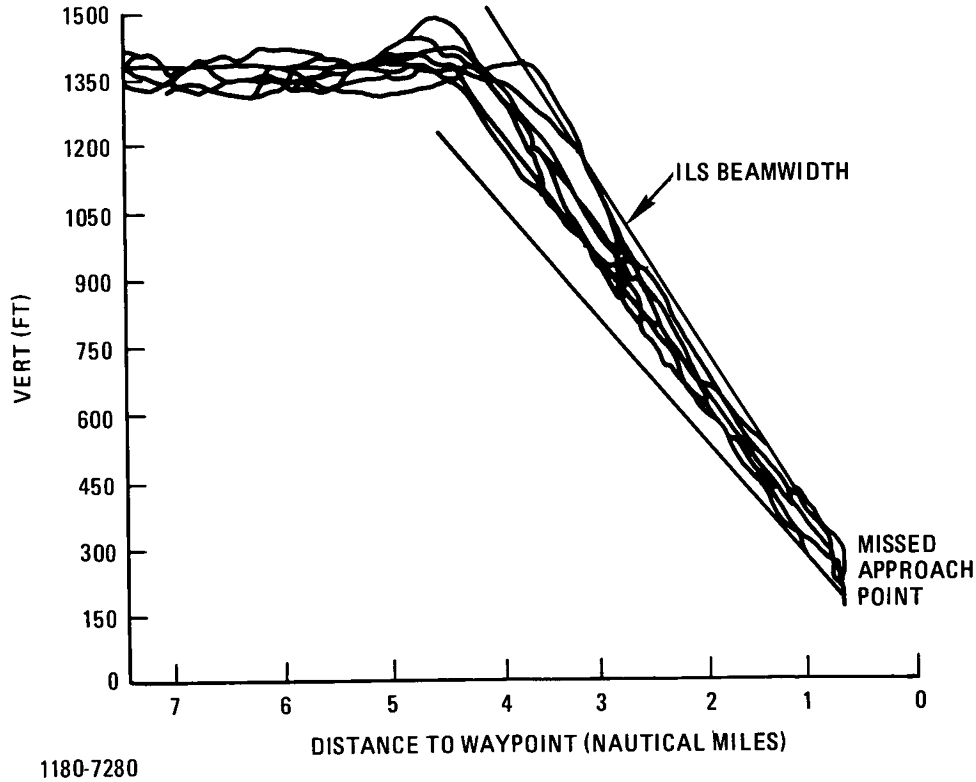

Figure 5. UH1 Landing Approach with a NAVSTAR X Set and PSD.

One of the unexpected results of the field testing is that the Z-set accuracy is better than anticipated. This result prompted a decision by DoD to "corrupt" the C/A signal in the operational GPS to limit navigation accuracy to approximately 150 meters.

Z-Set Performance

Z-set field test results are shown in Figure 4. The accuracy of a C/A signal set demonstrated remarkable performance. Also shown is the ability to navigate with three satellites coupled with altitude as the fourth input. This would imply that civil use can become widespread as soon as 3 satellites are in view most of the time. This coverage could occur as early as late 1985.

Landing Approaches

GPS sets have the capability for operator entry of 3-D waypoints into computer memory so that steering information (range, bearing and time-to-go) can be computed from one waypoint to the next. The X-set, in particular, uses this information to drive a Pilot Steering Display (PSD) which displays horizontal and vertical deviation from the intended flight path between waypoints. If key landing approach points are entered as Navstar waypoints, the pilot is provided with a self-contained, landing-approach instrumentation system which is independent of ground controllers or equipment.

Tests in a UH1 helicopter demonstrating landing approaches were conducted at the Yuma Test Range and results are shown in Figure 5. Note that all test approaches penetrated an imaginary Instrument Landing System (ILS) window at decision height. Conclusions from the test program are:

- Current GPS accuracies are adequate to steer aircraft on non-precision type (Tacan, Vor, ASR) approaches to landing.
- Pilot can execute an approach independent of ground control and ground equipment, provided he knows coordinates and altitudes of key approach points.
- Studies show that a GPS set at the runway with a data link to the GPS-equipped aircraft will eliminate several system errors (ephemeris, clock, atmosphere) and permit precision type (ILS, MLS, PAR) approaches to landing.

Rotor Modulation

In November of 1978, UH1 rotor modulation tests were conducted at the Yuma Test Range in a scenario depicted by Figure 6.

An X-Set antenna was located at positions 6-20 feet from the rotor shaft and GPS signals were received through the spinning rotor. Modulation effects from the rotor resulted in a

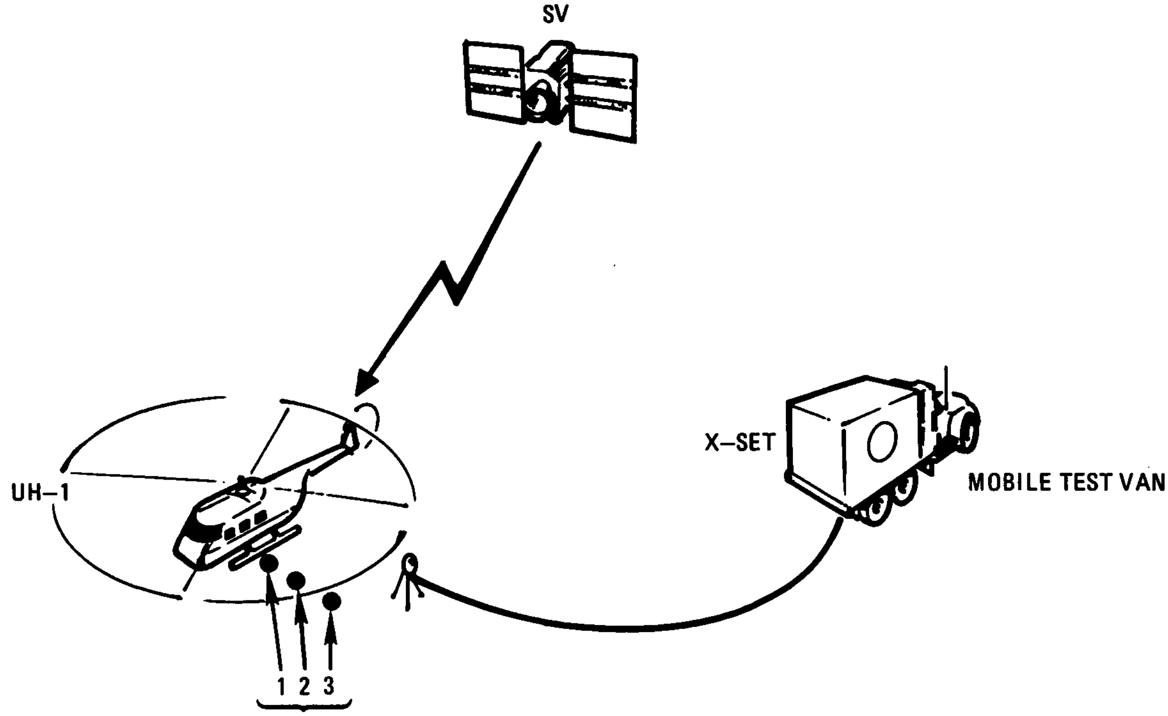

Figure 6. UH1 Rotor Modulation Test Scenario

net power increase in the received GPS signal and a 2-10 dB variation in the received signal/noise ratio. No navigation performance degradation was detected.

Foliage Attenuation

In December 1978 the U.S. Army conducted qualitative foliage attenuation testing in light-to-medium foliage at Eglin Air Force Base. The ability of the Manpack to obtain a static fix at a surveyed position was assessed as a function of satellite elevation. It was generally found that the Manpack had no difficulties with satellites at or above twenty degrees of elevation. A "rule of thumb" that seemed to emerge from the testing is that GPS signals can be received under foliage through which some sky is visible.

Differential GPS

The need to provide a higher degree of accuracy for precision approaches than that available from GPS led to the concept of differential navigation. Within the civil community the payoff for differential GPS is at least threefold:

- Improved position and velocity performance over conventional GPS Sets.

- Utility with limited satellite visibility or incomplete satellite constellation.

Figure 7 illustrates this concept. A GPS receiver is located on a surveyed point where X, Y and Z system errors can be identified and corrections determined. These corrections are data linked to aircraft which operate in the same geographical area and are, therefore, subject to the same errors. The X, Y & Z corrections obtained from the reference receiver are combined with the aircraft receiver solution thereby improving the position accuracy of the aircraft.

Results of differential navigation tests at Yuma in January 1980 are shown in Table 4. As noted on the chart, regardless of the magnitude of the GPS system error, the corrected solution error was less than three meters in the X, Y & Z axes.

TABLE 4. Differential GPS Test Results

POSITION	UNCORRECTED ERROR (M)	CORRECTED ERROR (M)
X	28	2.6
Y	21	2.7
Z	11	2.7

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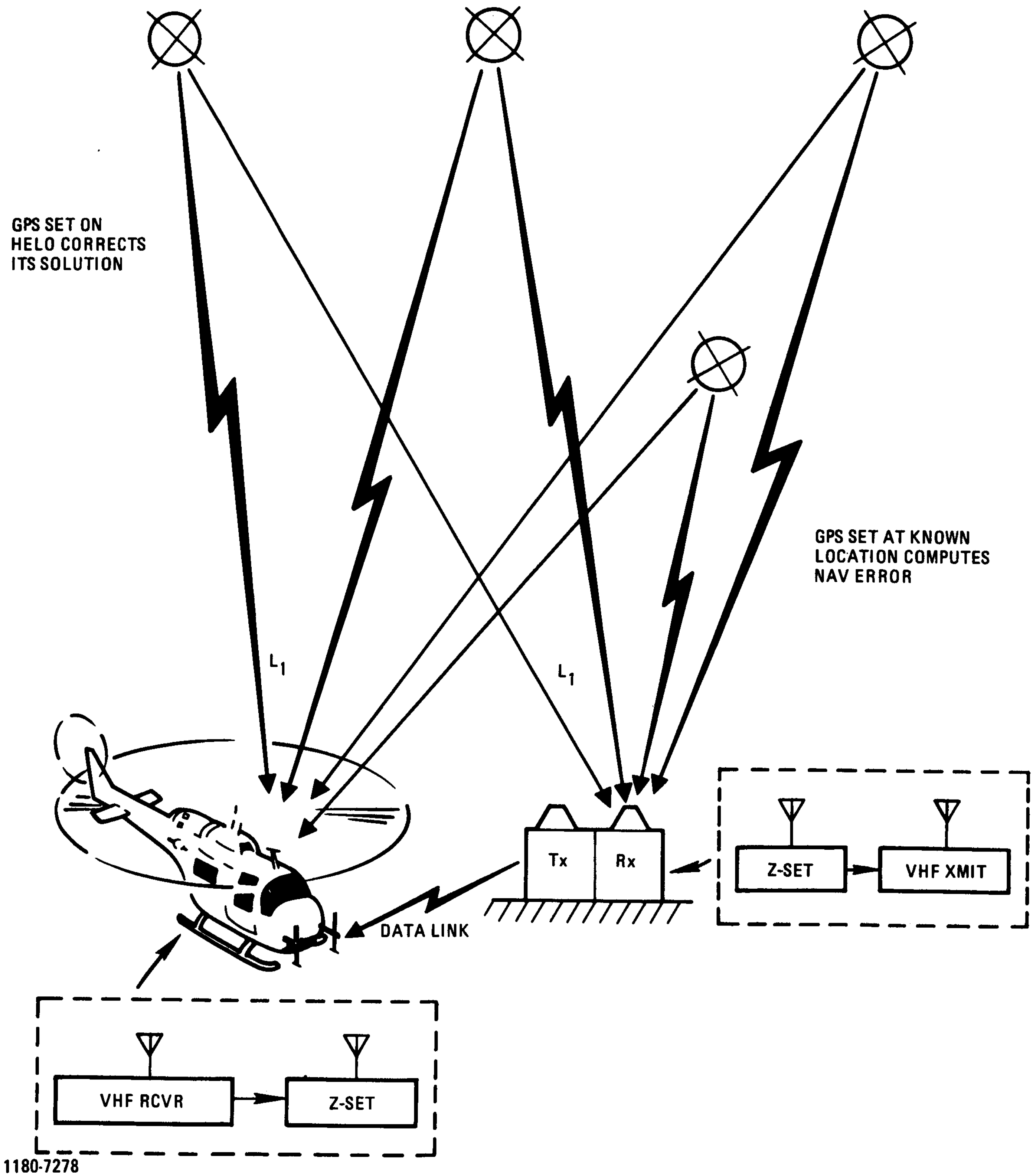

Figure 7. GPS Differential Navigation

In the near future, the concept of differential GPS which has been validated by field test data should be expanded by a study to determine the optimum system architecture for civil applications. This study should lead to a practical implementation of differential GPS hardware for use in the 1985 timeframe.

LOW COST CIVIL SET

Looking to the future, Magnavox recently completed a study for NASA-Langley Research Center which addressed the basic GPS set requirements for civil applications in light of present objectives and constraints. Alternatives for the equipment architecture were evaluated and a low cost implementation was projected based on applicable component technology available now and in the future.

To meet the needs of a wide range of GPS users, different equipment configurations were tailored to specific segments of the general aviation community by combining a basic GPS unit with auxilliary equipment to provide additional capability.

The basic unit shown in Figure 8 forms the architectural base for mass production of common modules. It contains the receiver/processor and control/display functions and provides a digital display of 3-D position plus ground speed, ground track and precise time. Distance and bearing to nine manually entered waypoints has been included to add to the general utility of the set. The basic set package is a standard 3.25" x 3.25" x 9" aircraft instrument case with an estimated weight of 3 lbs. and power requirement of 5 watts.

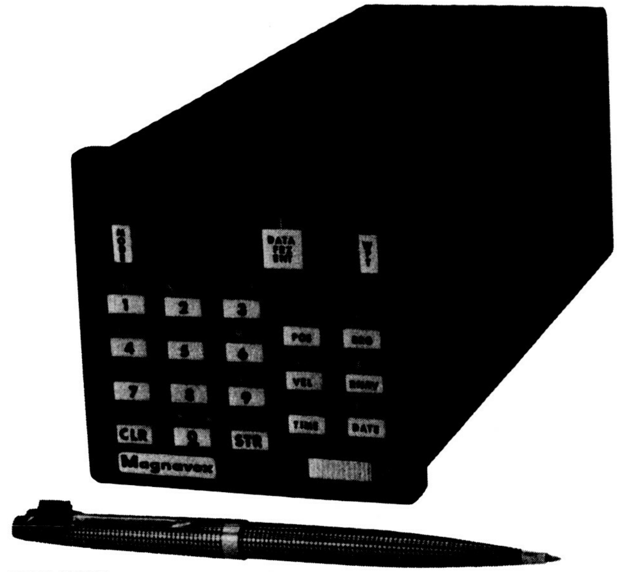

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Figure 8. Low Cost NAVSTAR Set.

Performance characteristics of this candidate design have been determined with a high degree of confidence through the use of computer simulations. Models for the major set functions, as well as the external environment, have been derived from tried and proven techniques used during the GPS Phase I User Equipment development and validated by actual equipment testing.

Figure 9 shows the horizontal position error on one of the simulations. Throughout the turn, position spikes can be seen

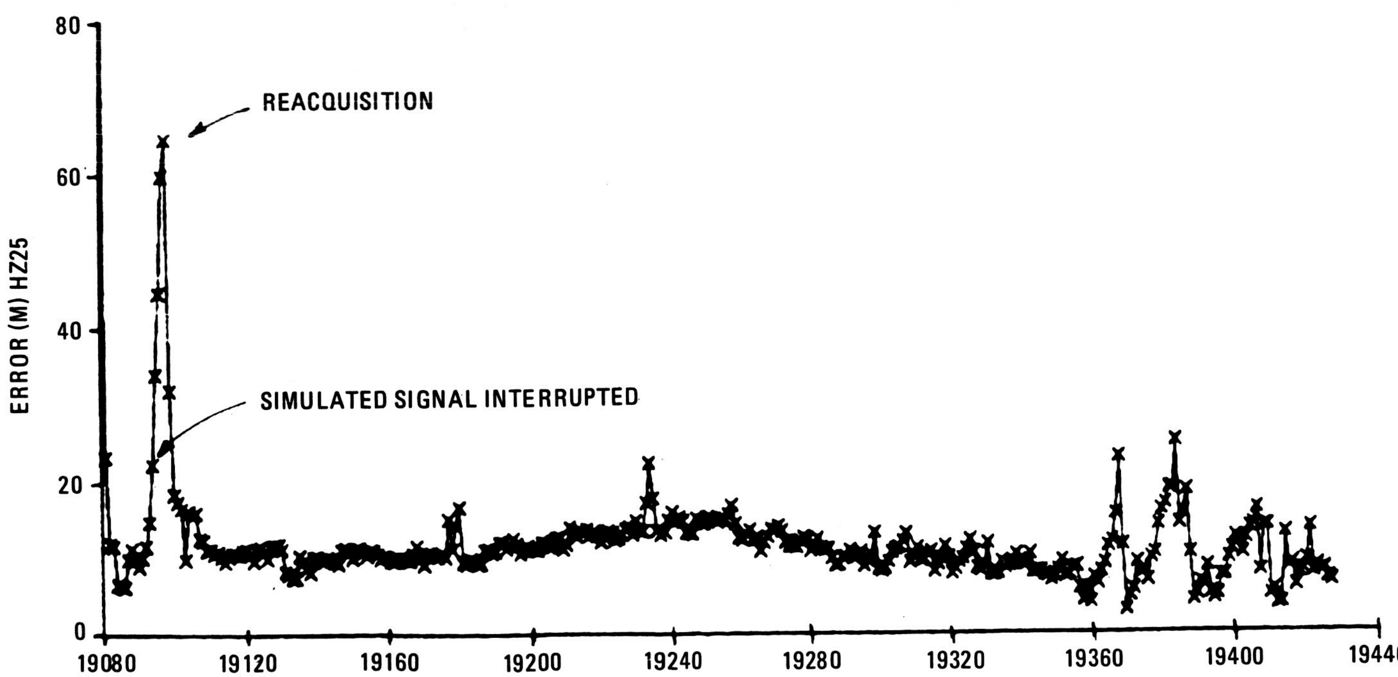

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Figure 9. Horizontal Position Error Magnitude

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as various satellites are shaded and then replaced. Near the beginning and end of the plot, error spikes are the result of model limitations.

Although much work remains to optimize set architecture, partitioning, component technology and human interfaces, the low cost civil set described in this report is a logical candidate for a future GPS-based helicopter RNAV and terminal guidance system. This GPS-based system could be an advantageous replacement for the VOR/DME (VORTAC) system by the end of this century. Its worldwide coverage, fail-safe features and signal reliability have distinct advantages over Loran C. Its excellent accuracy and immunity to atmospheric disturbances are obvious advantage over Omega.

HELICOPTER APPLICATIONS

GPS has the necessary attributes to become the primary civil air navigation aid in the late 1980's and beyond. GPS could, for instance, provide the precision position and velocity inputs to optimize the following functions:

RNAV	– 4-D navigation (navigation to desired point in space and time)
	– Continuous, Global Coverage
Approach, Landing, and Departure	– 4-D Terminal Guidance from RNAV transition to landing
	– 4-D Departure Guidance from takeoff to enroute RNAV
	– Runway identification and taxi guidance
	– Improved/unimproved landing site operations
	– All weather, o/o ceiling operation
ATC	– Aircraft separation, sequencing, and surveillance
	– Executive control of airspace
Collision Avoidance	– Accurate relative position
	– Minimum separation distances with safety

For helicopters, most of the above apply and are particularly pertinent to economical growth of heliports and to helicopter operations in congested areas and at confined or remote sites, such as offshore drill rigs, disaster areas, and exploration sites.

TECHNOLOGY DEVELOPMENT

GPS has the potential for becoming the primary navigation aid for helicopters (and civil air in general) in the late 1980's and beyond. Key technologies which should be investigated and developed in the interim include the following:

GPS Set Architecture and Interfaces – Testing and evaluation of GPS performance should be conducted to determine optimum approaches to several set parameters, such as number of channels, design of filters, antenna location and quantity, satellite tracking algorithms, and display and data link interfaces.

4-D Navigation – 4-D navigation capability should be developed and doctrine established for its use in RNAV, terminal and departure guidance, and ATC operations to insure that full advantage is taken of GPS for improved collision avoidance and efficient use of air space.

Differential GPS – A program is required to develop and evaluate differential GPS for terminal guidance operations. This technique has the potential for supporting precision landings independent of other systems. It would maximize the benefits to be derived by the civil community from GPS. Elements which should be studied include performance, correction algorithms, data links, coverage limitations, and doctrine.

Attitude Determination – GPS can be utilized to determine attitude through the use of multiple antennas. Thus, GPS might provide not only position, velocity, and time but also attitude. Current analysis indicates that attitude determination to a few milliradians may be possible. A program should be undertaken to develop and evaluate the technique for helicopters.

Displays – Investigations should be made to determine optimum display formats to exploit fully GPS's capabilities for 4-D navigation as applied to RNAV, approach and landing, and ATC.

Data Links – Studies should be conducted to investigate data link alternatives for voice and automatic data exchange to maximize GPS's capabilities for collision avoidance and executive control of airspace.

CONCLUSIONS

GPS has the potential for becoming the primary navigation aid for the civil air community in the late 1980's and beyond. A technology program as outlined above should be undertaken now to insure that GPS's full potential for improved helicopter operations in remote and congested areas under all weather conditions is realized when GPS becomes fully operational.

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LARRY K. CLARK

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